MRR 2000-4

New Nouveau
Brunswick

Mineral Resource Report

CURRENT RESEARCH *1999*

Edited by
Barbara M.W. Carroll

ISSN 0713-2433
ISBN 1-55236-754-1
Price $15.00

2000

Mineral Resource Report 2000-4

Current Research *1999*

Cover Illustration: Index to papers in this volume:

1. Geology and geophysics, Kedgwick area, NTS 21 O/11E (Carroll)
2. Preliminary sequence stratigraphy of the Horton Group (Keighley)
3. Late-glacial Coleoptera from Saint John, part of NTS 21 G/1 (Miller)
4. New U–Pb ages from southern New Brunswick (Miller, Barr, Fyffe, White)
5. Till geochemistry and glacial dispersal, Woodstock area, part of NTS 21 J/04 (Seaman)
6. Petrological / geochemical study of a section through the Pabineau deposit, part of NTS 21 P/05W (Walker)
7. Geology of the Popelogan Lake–Lost Pine Lake area, NTS 21 O/15a and b (Wilson)

Bathurst Mining Camp

This report has been prepared by:

Minerals and Energy Division
Department of Natural Resources and Energy
Province of New Brunswick

Hon. Jeannot Volpé
Minister of Natural Resources and Energy

New Nouveau
Brunswick

Natural Resources and Energy
Minerals and Energy

LEGISLATIVE LIBRARY
BIBLIOTHEQUE DE L'ASSEMBLÉE
LEGISLATIVE

NOV 2 2 2000

FREDERICTON, N.B.

Mineral Resource Report 2000-4

Current Research
1999

Edited by
Barbara M.W. Carroll

ISSN 0713-2433
ISBN 1-55236-754-1

2000

Recommended citation:

CARROLL, B.M.W. (editor) 2000. Current Research 1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, 165 p.

A sample recommended citation for individual papers:

CARROLL, J.I. 2000. Geology and geophysics of the east half of the Kedgwick map area (NTS 21 O/11 east), northern New Brunswick. *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 1–16.

TABLE OF CONTENTS

1–16 | Geology and geophysics of the east half of the Kedgwick map area (NTS 21 O/11 east), northern New Brunswick †††
J.I. Carroll, Geological Surveys Branch, New Brunswick Department of Natural Resources and Energy

17–29 | A preliminary sequence stratigraphy of the Horton Group, southeastern New Brunswick: interpretation of theDawson Settlement Member of the Carboniferous Albert Formation, Shell Albert Mines #4 well.
D. Keighley

31–38 | Late-glacial (Younger Dryas) Coleoptera from Saint John, New Brunswick (NTS 21 G/1) ‡‡
R.F. Miller, Steinhammer Palaeontology Laboratory, New Brunswick Museum

39–50 | New U–Pb ages from southern New Brunswick: preliminary results. ††
B.V. Miller[1], S.M. Barr[2], L.R. Fyffe[3], C.E. White[4]
[1] Department of Geology, University of North Carolina
[2] Department of Geology, Acadia University
[3] Geological Surveys Branch, New Brunswick Department of Natural Resources and Energy
[4] Nova Scotia Department of Natural Resources

51–71 | Till geochemistry and glacial dispersal in the eastern part of the Woodstock (NTS 21 J/04) map area, Carleton County, New Brunswick †
A.A. Seaman, Geological Surveys Branch, New Brunswick Department of Natural Resources and Energy

73–90 | A petrological / geochemical study of a section through the Pabineau sulphide deposit, Bathurst Mining Camp, New Brunswick (NTS 21 P/05W) ‡
J.A. Walker, Geological Surveys Branch, New Brunswick Department of Natural Resources and Energy

91–136 | Geology of the Popelogan Lake–Lost Pine Lake area (NTS 21 O/15a and b), Restigouche County, New Brunswick†††
R.A. Wilson, Geological Surveys Branch, New Brunswick Department of Natural Resources and Energy

137–165 | Index to 1999–2000 publications on the geology of New Brunswick

† New Brunswick Geological Surveys Branch ordinary budget
†† New Brunswick Geological Surveys Branch ordinary budget and a research grant to S.M. Barr from NSERC
††† Appalachian Foreland and Platform NATMAP project
‡ EXTECH-II (New Brunswick Geological Surveys Branch ordinary budget)
‡‡ New Brunswick Museum ordinary budget and NGS research grant

All translations were provided by the Translation Bureau,
New Brunswick Department of Supply and Services

Tous les traductions ont été préparées par le Bureau de traduction,
Ministère de l'Approvisionnement et des Services du Nouveau-Brunswick

101-01776/

GEOLOGY AND GEOPHYSICS OF THE EAST HALF OF THE KEDWICK MAP AREA (NTS 21 O/11 EAST), NORTHERN NEW BRUNSWICK †††

J.I. Carroll
New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,
P.O. Box 50, Bathurst, New Brunswick, CANADA E2A 3Z1 (e-mail: jeff.carroll@gnb.ca)

CARROLL, J.I. 2000. Geology and geophysics of the east half of the Kedgwick map area (NTS 21 O/11 east), northern New Brunswick. *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 1–16.

The eastern half of the Kedgwick map area is divisible into eastern and western domains separated by the north-northeasterly striking McKenzie Gulch Fault. East of this fault lie Ordovician and Silurian carbonate rocks of the Matapédia Group and quartzose sedimentary rocks of the Upsalquitch Formation. West of the fault, rocks of the Ordovician Grog Brook Group underlie the area. A new unit (Pat Brook beds) is recognized in the eastern domain. The Pat Brook beds are an assemblage of grey–green pebble conglomerate with a high proportion of mafic and black shale clasts, interbedded with grey–green sandstone and siltstone that are underlain by rocks of the Balmoral Group.

West of the McKenzie Gulch Fault, within the Grog Brook Group, three new units are identified: (1) a *mudstone-dominated unit* overlain by (2) a *carbonaceous shale unit* and (3) an upper and partially crosscutting *sandstone-dominated unit*. The mudstone-dominated unit consists of 60–90% medium-bedded, siltstone and shale with bedforms indicative of deposition by low-energy turbidite flows. The carbonaceous shale unit is a dark grey to black, rhythmically bedded, moderately sulphidic unit deposited in a low energy, anoxic environment. The overlying sandstone-dominated unit consists of medium-grey sandstone representing channel-fill and overbank deposits.

The new units are defined on the basis of field investigation and airborne geophysical data. The mudstone-dominated unit has a greater proportion of radiogenic elements than the adjacent units. The carbonaceous shale unit is conductive and is traceable via apparent conductivity. The first vertical derivative of the magnetic data is useful in the definition of internal structures in all represented units. A large, 9 x 5 km, total field magnetic anomaly is located in the central part of the map area and indicates the presence of a buried structure that may have economic potential for Ni and Cu.

On peut subdiviser la moitié orientale du secteur cartographique de Kedgwick en domaines oriental et occidental séparés par la faille orientée dans une direction nord-nord-est du ravin McKenzie. Des roches carbonatées ordoviciennes et siluriennes du groupe de Matapédia et des roches sédimentaires quartzeuses de la Formation d'Upsalquitch se trouvent à l'est de cette faille. À l'ouest de la faille, le secteur s'appuie sur des roches du groupe de l'Ordovicien du ruisseau Grog. Les géologues reconnaissent une nouvelle unité (strates du ruisseau Pat) dans le domaine oriental.

---

††† Contribution to the Appalachian Foreland and Platform NATMAP project.

Les strates du ruisseau Pats constituent un assemblage de conglomérats de cailloux gris–vert comportant une proportion élevée de clastes schisteux noirs et mafiques, interstratifiés de grès et de siltstone gris–vert recouvrant des roches du groupe de Balmoral.

Trois nouvelles unités sont définiesà l'ouest de la faille du ravin McKenzie à l'intérieur du groupe du ruisseau Grog: 1) une *unité à prédominance de mudstone* recouverte par 2)une *unité de schiste carboné* et 3) une *unité à prédominance de grès* supérieure et partiellement transversale. L'*unité à prédominance de mudstone* est constituée dans une proportion de 60 à 90 % de siltstone et de schiste en strates moyennes dont les conformations témoignent de l'accumulation de coulées de turbidite de faible énergie. L'*unité de schiste carboné* est une unité moyennement sulfurée à stratification rythmique variant du gris foncé au noir qui s'est déposée dans un environnement anoxique à faible énergie. L'*unité* sus-jacente *à prédominance de grès* est constituée de grès gris moyen représentant des dépôts alluviaux d'inondation et d'alluvions sédimentés dans le chenal.

On a défini les nouvelles unités en s'appuyant sur des données géophysiques aériennes et des études sur le terrain. L'*unité à prédominance de mudstone* comporte une proportion d'éléments radiogéniques supérieure aux unités adjacentes. L'*unité de schiste carboné* est conductrice et on peut la retracer au moyen de sa conductivité apparente. La première dérivative verticale des données magnétiques est utile dans la définition des structures internes de toutes les unités représentées. On relève une anomalie magnétique du champ total marquée de 9 sur 5 km dans la partie centrale du secteur cartographique; cette anomalie révèle la présence d'une structure enfouie qui pourrait présenter un potentiel économique de Ni et de Cu.

INTRODUCTION AND PREVIOUS WORK

The northwestern part of New Brunswick is currently the focus of a multi-disciplinary study to evaluate the resource potential and the tectonostratigraphic history of the Gaspé Belt (Figure 1). The work is part of a regional NATMAP project termed 'Appalachian Foreland and St. Lawrence Platform Architectures in Quebec, New Brunswick and Newfoundland'. The work will involve four NTS map sheets (NTS 21 O/11, 12, 13, and 14) over the next four years and is co-funded by the New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch and the Geological Survey of Canada. The project consists of five geological transects, two of which extend into northern New Brunswick. Work in the New Brunswick component will involve the southern parts of Transects 3 and 4 (Figure 1). Transect 3 (Matane–Restigouche) extends south from Matane, Québec and covers parts of the Aroostook–Percé Anticlinorium and Connecticut Valley–Gaspé Synclinorium of the Gaspé Belt and is the focus of the work described herein. Additional work on Transect 4 is ongoing by J. Langton and R. Wilson of the Geological Surveys Branch.

Previous mapping of parts of the Gaspé Belt in northwestern New Brunswick has been undertaken at various scales by Alcock (1935), Hamilton-Smith (1970), St. Peter (1978) and Irrinki (1990). Within the Kedgwick (NTS 21O /11) map area, the most detailed account can be found in St. Peter (1978) who originally defined the Grog Brook Group. Most recently, Giggie (1998) completed a 1:100 000-scale compilation of previous mapping. This work was undertaken as follow-up to Phase I of the Restigouche multiparameter airborne geophysical survey (Giggie 1999). Stream-sediment geochemistry was completed as part of Phase I by Pronk and Frisk (1999) and highlighted a significant Ni, Cu and Co anomaly in the Kedgwick map area.

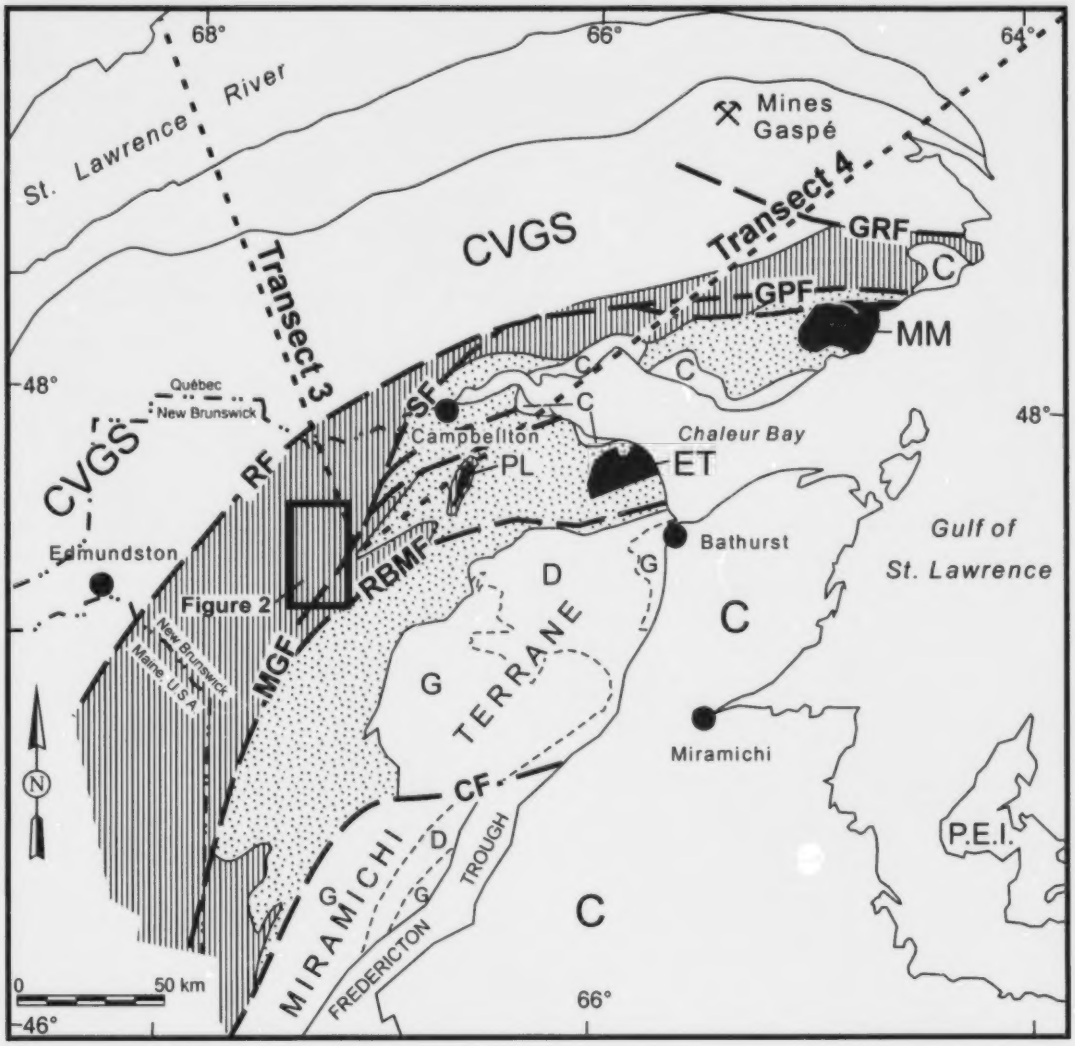


Figure1. Major geological divisions of northern New Brunswick and Gaspé, Québec showing the location of the east half of the Kedgwick (NTS 21 O/11E) map area (Figure 2). The Aroostook–Percé Anticlinorium is shown in vertical hatching and the Chaleur Bay Synclinorium in stipple pattern.Dark-shaded areas are inliers that predate Late Ordovician to Middle Devonian rock of the Gaspé Belt: **MM**—Macquereau–Mictaw inlier (Dunnage and Humber zones); **ET**—Elmtree inlier (Dunage Zone); **PL**—Popelogan inlier (Dunnage Zone); **H**—Humber Zone; **CVGS**—Connecticut Valley–Gaspé Synclinorium; **G**, **D**—Gander and Dunnage zone rocks, respectively, in the Miramichi Terrane; **C**—Carboniferous cover. Regional faults: **RF**—Restigouche Fault, **GRF**—Grande Rivière Fault, **GPF**—Grand Pabos Fault, **SF**—Sellarsville Fault, **MGF**—McKenzie Gulch Fault, **RBMF**—Rocky Brook–Millstream Fault, **CBF**—Catamaran Brook Fault. Transects 3 and 4 are part of the NATMAP/ Geological Bridges of Eastern Canada program.

Private sector work has been intermittent from 1970 to the present. A total of 18 assessment reports have been filed, reporting on soil geochemistry, prospecting and ground geophysics. Keevil Mining Corp. (Fraser 1969) flew a small airborne magnetic survey in 1968–69 with no significant results. The porphyry-skarn and gold potential were the main impetus for the work. No drilling or trenching has been reported

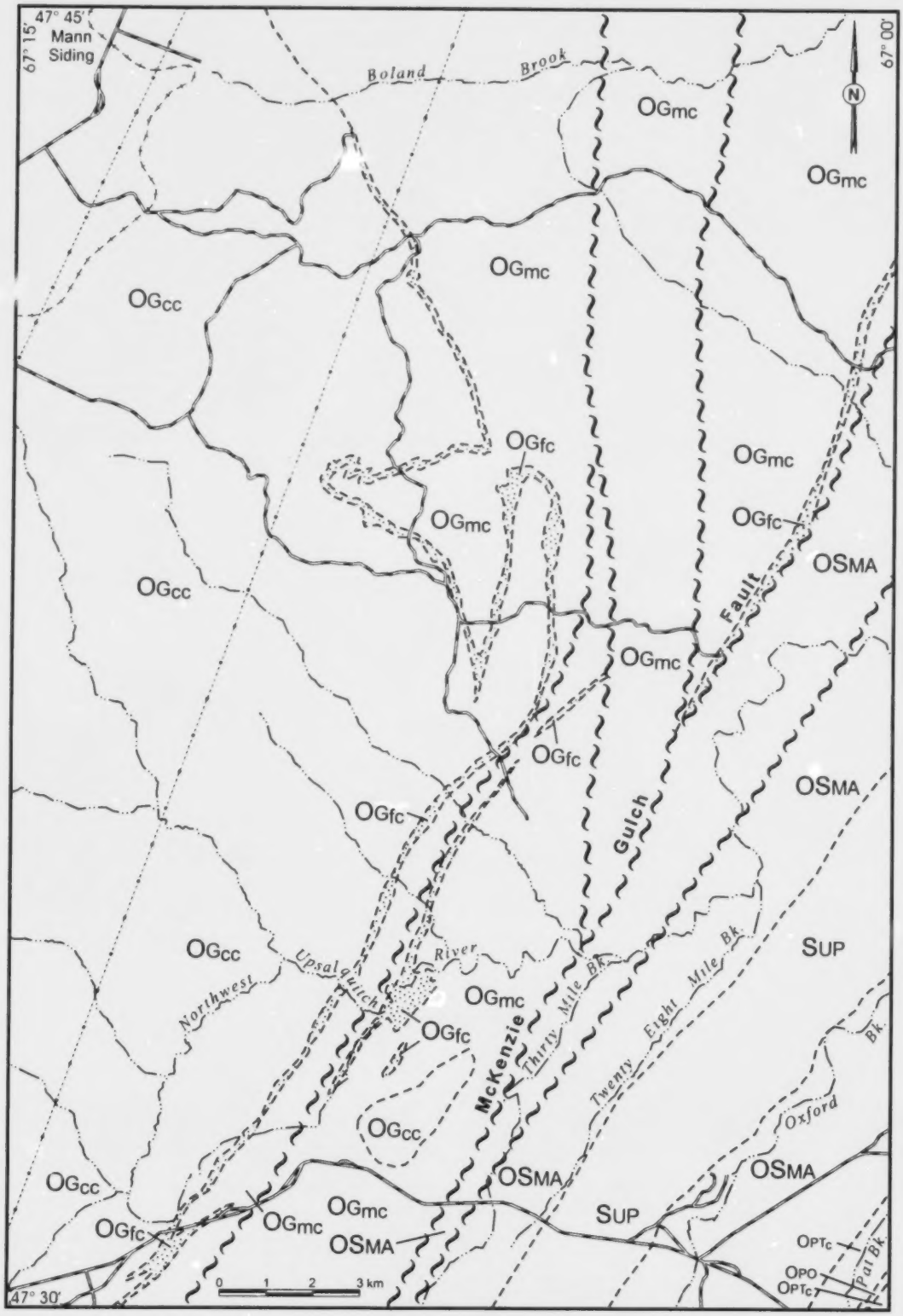


Figure 2. Geological map of the east half of the Kedgwick (NTS 21 O/11) map area, New Brunswick.

in the Kedgwick map area. Current work by Wayne Lockhart is focusing on the nickel and copper potential of the area, and is aided by the airborne and stream geochemistry surveys undertaken in 1998.

This paper discusses the preliminary results of mapping in the eastern part of the Kedgwick (NTS 21 O/11) map area. The airborne geophysical surveys provide a unique opportunity to better subdivide the bedrock geology and assess the palaeostratigraphic setting and tectonic history of the basin as well as investigate the mineral potential of northwestern New Brunswick.

STRATIGRAPHY

The rocks underlying the study area are a mixed assemblage of deep-water siliciclastic and calcareous sedimentary rocks deposited in a fore-arc successor basin following the Taconian Orogeny; this basin existed until the onset of the Early to Middle Devonian Acadian Orogeny (Bourque *et al.* 1995; Malo and Bourque 1993).

The eastern half of the Kedgwick map area is divisible into eastern and western domains that are separated by the north-northeasterly striking McKenzie Gulch Fault. Rocks of the Balmoral Group, Matapédia Group and Upsalquitch Formation, in ascending stratigraphic order, underlie the eastern domain. West of the fault, rocks of the Late Ordovician Grog Brook Group underlie the area (Figure 2).

LEGEND

EARLY SILURIAN

SUP — UPSALQUITCH FORMATION: Micaceous, commonly bioturbated and fossiliferous, noncalcareous to weakly calcareous siltstone and fine-grained sandstone: local thin to moderately thick beds of calcarenite.

LATE ORDOVICIAN - EARLY SILURIAN

MATAPÉDIA GROUP

OSMA — Thin- to medium-bedded dark grey to blue-grey argillaceous limestone, commonly intercalated with thin- to medium-bedded calcareous shale: minor weakly calcareous siltstone and shale.

LATE ORDOVICIAN

GROG BROOK GROUP

OG_{cc} — Sandstone dominated Unit: Thick- to medium-bedded, moderately mature, weakly calcareous, fine- to medium-grained sandstone intercalated with thin-to medium-bedded, noncalcareous siltstone and minor shale.

OG_{fc} — Carbonaceous Shale Unit: Dark grey to black, thinly bedded and finely aminated shale and siltstone: local very thin beds of very fine-grained, weakly pyritiferous sandstone.

OG_{mc} — Mudstone dominated Unit: Thick- to medium-bedded, noncalcareous siltstone and shale interbedded with thin-bedded, weakly calcareous to noncalcareous, fine-grained sandstone.

OPT_c — PAT BROOK BEDS: Medium- to thick-bedded, noncalcareous, fine-grained sandstone and local pebbly sandstone and immature conglomerate.

BALMORAL GROUP

OPO — POPELOGAN FORMATION: Black graphitic chert and slate.

SYMBOLS

Geological contact

Fault

Road

River or Brook

Hydro transmission line

Railway line (abandoned)

Balmoral Group

Popelogan Formation

The oldest rocks identified in the map area are grey–black to black Caradocian slates and cherts assigned to the Popelogan Formation (Philpott 1988). These rocks are very poorly exposed in the extreme southeast corner of the map area and lie along the core of a northeasterly trending, upright anticline. The latter is interpreted to be an extension of the Popelogan anticline, which lies 45 km along strike to the northeast and is the type area of the Balmoral Group. A detailed description of the Balmoral Group is provided by Wilson (this volume).

Pat Brook Beds: Overlying the Popelogan Formation are siliciclastic sedimentary rocks herein referred to as the Pat Brook beds, which crop out along recently constructed logging roads immediately east of Pat Brook in the southeast corner of the map area (Figure 2). The unit consists of grey–green fine-grained conglomerate and thin- to medium-bedded (5–15 cm) medium- to coarse-grained sandstone. The composition of the clasts reflects a mafic source although shale clasts locally occur, the latter presumably from an intraformational source or possibly a contribution from the underlying Popelogan Formation. The total thickness of the unit is poorly constrained since the upper and lower contacts are not exposed. Previous work by St. Peter (1978) interpreted the Pat Brook rocks as part of the Grog Brook Group; however, they do not lithologically resemble the Grog Brook sandstones, which have a higher degree of compositional maturity and a greater feldspathic component. Instead, the Pat Brook beds resemble some facies of the Garin Formation (Honorat Group) in the Gaspé Peninsula of Québec (Malo 1988). Additional stratigraphic information is required before the formation can be definitively assigned to the Balmoral, Grog Brook or Honorat Groups.

Grog Brook Group

The Grog Brook Group underlies the main part of the map area and comprises Late Ordovician interbedded sandstone, siltstone, shale and minor conglomerate (St. Peter 1978). Numerous exposures are documented along Hwy. 180 and along deeply incised stream valleys throughout the map area. The total thickness of the Grog Brook Group is estimated by St. Peter (1978) at 7600 metres based on schematic cross-sections. A first attempt is made herein to subdivide the Grog Brook Group into lithostratigraphic units based on detailed field investigation of the airborne geophysical anomalies. Three sub-units (Figure 2) are identified in the area; from oldest to youngest, they are: (1) a mudstone-dominated unit; (2) a carbonaceous black-shale unit that conformably overlies the mudstone-dominated unit; and (3) a sandstone-dominated unit representing channel and proximal overbank deposits that may, in part, crosscut the other units. Formal naming of the new subdivisions will follow additional mapping to the north and west to better define their areal extent and type locations.

The *mudstone-dominated unit* consists of grey–black to dark grey (Munsell N2-N3) thin- to medium-bedded siltstone, argillite and shale with thin beds (2–10 cm) and laminae (1–5 mm) of fine-grained sandstone. Mudrock lithotypes typically account for between 60 and 90% of the rock, by volume. The unit is noncalcareous except in some sandstone beds and laminae where minor carbonate cement may be present. Load structures are common in thicker sandstone laminae and small beds, indicating deposition by small-scale turbidity currents (Figure 3). Thin laminae (1–2 mm) of black, carbonaceous mud are also present, although they are only volumetrically significant near the contact with the overlying carbonaceous shale unit. Biogenic debris has not been observed in this unit, although ichnofauna in the form of chondrites and planolites occur in places. Bedding orientation ranges from subhorizontal in the southern part of the map area to vertical in the tightly folded domains to the north. The latter area features several northerly

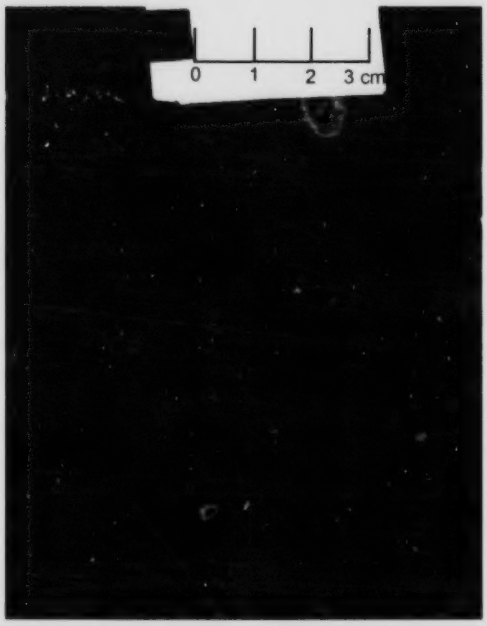


Figure 3. Thin sandstone beds (lighter) with load structures at their bases within the *mudstone-dominated unit*. Younging is toward the top of the photograph.

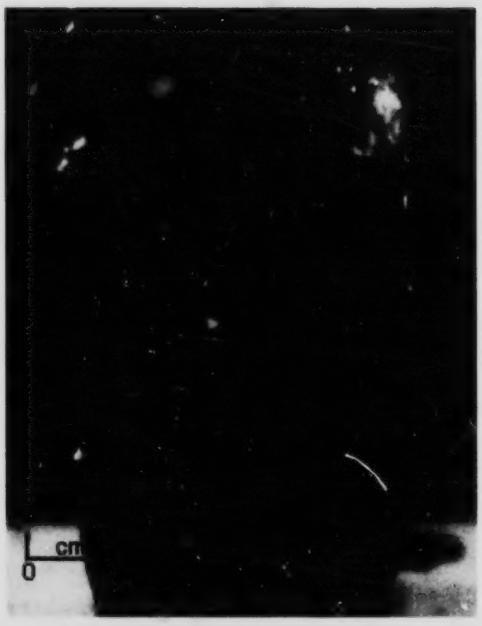


Figure 4. Rythmically bedded carbonaceous mud (dark) and dark grey siltstone (lighter) of the *carbonaceous shale unit*. Note the disseminated pyrite (white speckles) in the coarser beds concentrated along the main cleavage (vertical).

striking faults that merge with the McKenzie Gulch Fault near the centre of the map sheet. Structural complexity in the form of variable bedding orientations is associated with these faults. Trace amounts of pyrite are disseminated throughout the unit. The total thickness of the unit is undetermined because the subjacent rocks are not exposed.

The *carbonaceous shale unit* consists of thin-bedded (0.5–2 cm) grey–black to dark grey (Munsell N2-N3), parallel-laminated, nonbioturbated, siltstone and very fine-grained sandstone interbedded with thin-bedded (1–2 cm) black, carbonaceous, parallel-laminated shale (Figure 4). The maximum thickness of the lithotype can approach 60 m but typically ranges between 20 and 35 m. The unit is conformable with the underlying *mudstone-dominated unit* and the overlying *sandstone-dominated unit*. Typically, an increase in the number and thickness of carbonaceous shale beds and laminae mark the lower transition while an increase in amount and thickness of sandstone beds and a decrease in carbonaceous shale marks the transition into the overlying sandstone-dominated unit. In addition, the colour of both the sandstone and the siltstone becomes lighter (from N4 to N6 in the sandstone and from N2 to N4 / N5 in the siltstone) upon passing upward into the *sandstone-dominated unit*. The thickness of this transition zone can be as much as 100 m in some locations. Pyrite is the dominant accessory sulphide mineral and occurs as finely disseminated grains (0.1–0.5 mm) that are usually concentrated in the sandstone beds adjacent to the carbonaceous beds. The pyrite is probably diagenetic, although later remobilization has resulted in a preferred orientation of most pyrite particles parallel to the main cleavage (Figure 4). Massive pyrite layers (1–2 mm thick) locally occur within the coarser-grained beds and may be conformable with bedding

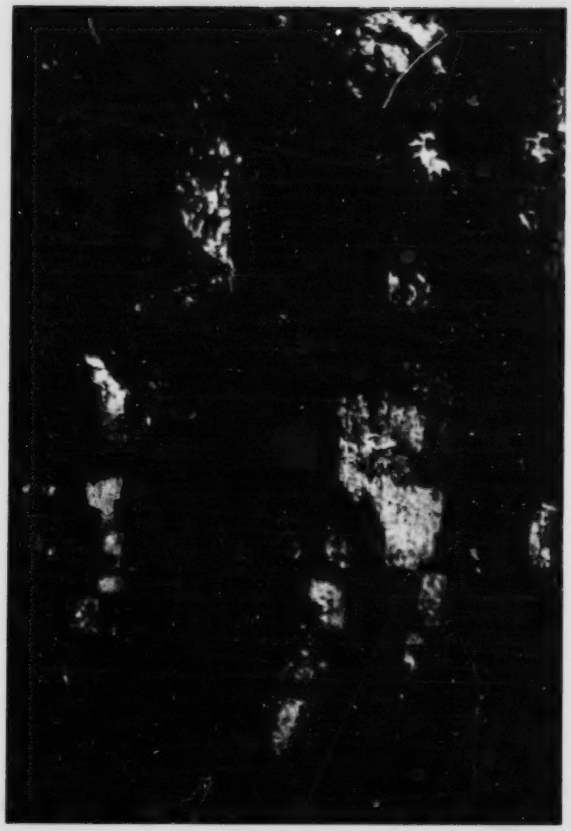
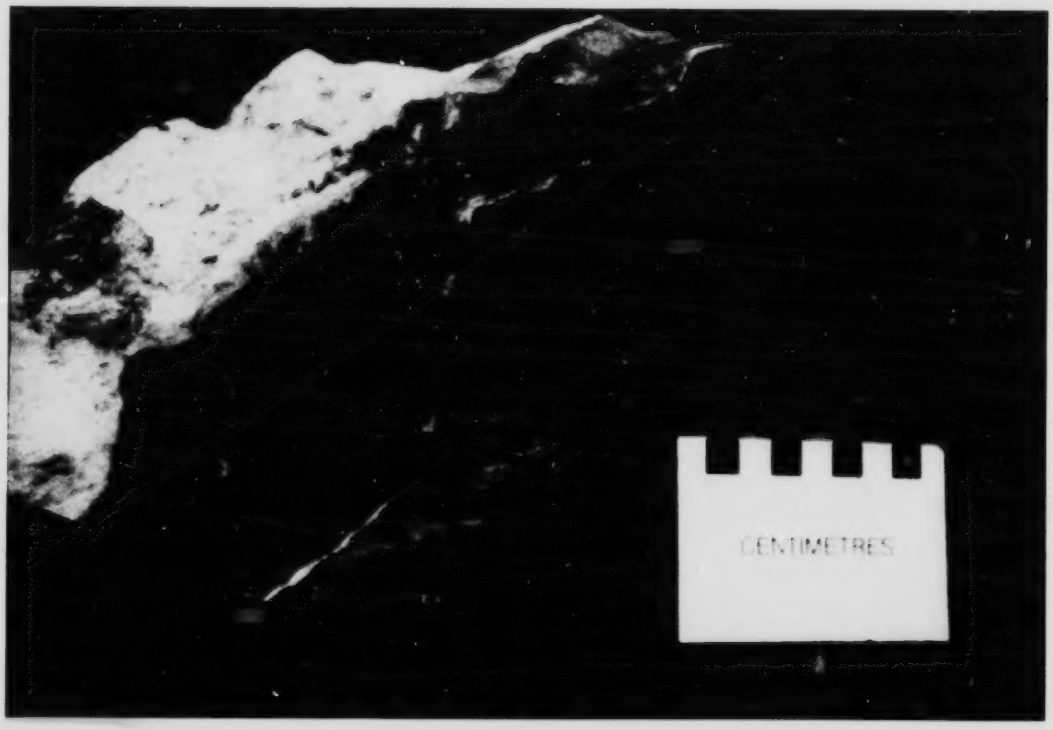


Figure 5. Fining-upward sequence of medium-bedded sandstone of the *sandstone-dominated unit*. Photograph represents approximately 3.5 m of vertical section.

Figure 6. Thin-bedded argillaceous limestone (slightly lighter) and calcareous siltstone of the Matapédia Group.



or cross-cut bedding in small-scale folds. The formation of these "pyrite beds" may be the result of pyrite replacement of specific laminae that had initial compositions especially favourable to pyrite formation (e.g., high reactive-iron content and carbonaceous material). While a hydrothermal origin cannot be ruled out, it seems unlikely because there is, as yet, no evidence of synsedimentary hydrothermal activity in the area. The carbonaceous nature of the shale makes it a possible "sink" for metals, a phenomena that is well documented world-wide (Arthur and Sageman 1994) and may be a contributing factor to the Ni and Cu anomalies reported in stream-sediment surveys by Pronk and Friske (1999). Further analysis is planned to investigate this possibility.

The *sandstone-dominated unit* consists of fine- to medium-grained, medium light grey to medium dark grey (Munsell N6 to N4) thin- to thick-bedded, variously micaceous sandstone interbedded with dark to medium grey (Munsell N3 to N5) thin- to thick-bedded siltstone and lesser shale (Figure 5). Bedforms typical of deposition by turbidity currents of varying scale are the rule and partial Bouma sequences are common (c to e intervals mainly). Load casts, flute casts, ball and pillow structures and scours are commonly identifiable in better sections. Overall, the sandstone lithotype volumetrically dominates but siltstone and shale may predominate locally. The sandstone is generally weakly calcareous on fresh surfaces reflecting the presence of calcareous cement, whereas the siltstone and shale are noncalcareous. The appearance of calcareous siltstone and shale marks the transition into the overlying Matapédia Group (Pabos Formation). Ichnofauna in the form of chondrites and planolites occur locally although a number of other forms have been documented elsewhere in the Grog Brook Group (Pickerill 1980). The sandstone-dominated facies is interpreted to be a proximal submarine channel and fan assemblage characterized by channel-fill and overbank deposits. Pyrite is common throughout the unit but in low concentration (typically, much less than 1%). Pyrrhotite occurs locally in some sandstone beds and these beds are traceable by the first vertical-derivative magnetic airborne anomalies.

Matapédia Group

The Matapédia Group is confined to the eastern part of the map area (Figure 2); it is interpreted as conformable with the underlying Pat Brook beds, but is in fault contact with the Grog Brook Group to the west along the regional, north-northeast-striking McKenzie Gulch Fault. The Matapédia Group is well-exposed in road-cuts along Hwy. 180 near Oxford, Twenty Eight Mile and Thirty Mile brooks. Excellent exposures are also found along the Northwest Upsalquitch River in the east-central part of the map area (Figure 2). The Matapédia Group is well documented in northwestern New Brunswick and in the Gaspé Peninsula (e.g., Skidmore 1965; Hamilton-Smith 1970; St. Peter 1978; Malo 1988; Wilson 1990) and is typically described as comprising thin-bedded to laminated argillaceous limestone, calcareous siltstone or shale with local arenaceous limestone and minor calcarenite (Figure 6). The most distinctive feature of the unit is its differential weathering. Argillaceous limestone (calcilutite) weathers a grey–tan colour in positive relief whereas the calcareous siltstone weathers a tan–brown colour in negative relief giving rise to the colloquial term "ribbon rock". The calcilutite beds range in thickness from 3 to15 cm and are volumetrically more significant higher in the section. Bedforms are typical of deposits laid down by turbidity flows in a slope environment and display parallel and locally convolute lamination. Very small-scale graded bedforms occur locally. The lower contact is poorly exposed but is interpreted to be gradational with the underlying Pat Brook beds east of the McKenzie Gulch Fault.

Structurally, the Matapédia Group occupies the core of a northeasterly trending syncline. The associated cleavage takes the form of an anastomosing fracture cleavage throughout most of the unit. Near the

McKenzie Gulch Fault a spaced (5–10 cm) anastomosing solution cleavage develops that, locally, is sufficiently strong to obliterate most of the primary bedding relationships.

The Matapédia Group in the Gaspé Peninsula has been subdivided into the lower Pabos Formation and the overlying White Head Formation (Malo 1988). The Pabos formation is dominated by calcareous siltstone and shale, fine-grained sandstone and lesser argillaceous limestone. The White Head Formation is dominated by thin-bedded argillaceous limestone (calcilutite) interbedded with calcareous mudrocks. The White Head Formation is probably the dominant unit represented within the Matapédia Group in the map area, although "Pabos-like" rocks are identifiable locally.

Upsalquitch Formation

The Upsalquitch Formation conformably overlies the Matapédia Group in the southeast part of the map area. It is moderately well exposed along Highway 180, immediately east of Twenty Eight Mile Brook (Figure 2). Smaller exposures are found along logging roads along strike to the northeast. The unit consists of medium- to thick-bedded (10–30 cm) calcareous siltstone/shale, calcareous micaceous sandstone, calcarenite and minor argillaceous limestone. Parallel and cross-lamination (1–10 mm) is common in fine-grained beds. Load casts, flute casts and complete (a–e) or truncated Bouma sequences are common, indicating turbidity current deposition. Fossil debris is common in some beds and identifiable macroscopically as crinoid ossicles and bryozoans. The unit is interpreted as a basal member of the Upsalquitch Formation and, hence, it is assigned to the informally named Arsenault Brook member (Wilson, this volume).

Intrusive rocks

Intrusive rocks in the east half of the Kedgwick map area include Siluro-Devonian mafic and felsic dykes that are commonly emplaced parallel to the regional McKenzie Gulch Fault. Felsic dykes are more common east of the fault while mafic dykes are more abundant west of the fault. The felsic dykes are well exposed along the Northwest Upsalquitch River and vary in thickness from 2 to 20 m in the east-central part of the map area and up to 100 m in thickness at the Legacy Cu-skarn deposit 3 km east of the map area (Moore and Lentz 1996). Typically, the felsic dykes are green–grey to tan–grey, feldspar porphyritic and weather a tan–orange colour, reflecting the presence of minor pyrite and iron-bearing silicate and carbonate minerals. Quartz porphyritic varieties are less common.

Mafic dykes are less abundant than felsic dykes in the map area. They are typically fine- to medium-grained, dark green to green–grey, phaneritic rocks varying in thickness from 2 to 6 m. Weathered equivalents are tan to brown–grey. Fine-grained margins (chilled) are typical where contact relationships can be observed. Primary minerals include plagioclase and pyroxene with lesser amounts of biotite, epidote and secondary calcite. Minor disseminated pyrite (< 1%) is common. All phases observed have low magnetic susceptibility (0.35 to 0.45×10^{-3} SI units) relative to their host rocks (0.29 to 0.50×10^{-3} SI units).

STRUCTURE

Regionally, two phases of deformation have been recognized in the Aroostook–Percé Anticlinorium. The first, D_1, is related to a regional uplift (Salinic Disturbance) generated by the cessation of northwestward subduction of the Tetagouche back-arc basin and initial docking of Avalonia with Laurentia in the Late Silurian (Malo and Bourque 1993). The second phase, D_2, is related to continued continental convergence of the Laurentian and Gondwanan plates associated with the Early to Middle Devonian Acadian Orogeny

(van Staal and de Roo 1995). Acadian dextral transpression initially produced open, upright folds within the basin and culminated with the formation of regional-scale dextral strike-slip faults (Malo and Bourque 1993). The Acadian event is probably responsible for the structures observed in the map area.

Regionally, the D_1 event is interpreted to have produced minor northwest-trending, open folds and minor, synsedimentary faulting (Malo and Bourque 1993). Northeast-trending, doubly plunging, open folding is the dominant geometry in the study area and is interpreted, regionally, as an effect of the Acadian Orogeny (D_2) (Malo and Bourque 1993). The lack of a well-developed S_1 cleavage (i.e., demonstrably crenulated by S_2) in the study area, precludes an absolute assessment of whether the doubly plunging nature of these folds is the result of an F_2/F_1 overprint or is the result of noncylindrical F_2 folding or both. The *carbonaceous shale unit* provides the best "marker" horizon in the map area both from a geological and geophysical perspective and illustrates the doubly plunging nature of the folds. The large "fish-tail" pattern in the central part of the map area represents a small dome structure with bedding dipping shallowly to the north along the northern limb, shallowly to the southwest along the southwest-facing limb, and subvertical along the eastern limb (Figure 2). The main cleavage (D_2) changes orientation from north-striking in the south to northwest-striking in the north indicating a progressive single event is responsible for the pattern. An overprinting of two separate deformational events would be expected to produce similar patterns elsewhere; however, this has not been observed to date.

The following discussion will refer to the Acadian deformation (D_2) as the "first" deformational event (e.g., D_1, F_1, etc.) since the effects of the earlier Salinic event are not noted in the area.

In the study area F_1 folds are open, upright and commonly doubly plunging with a well developed, northeast- to north-northwest-trending axial-planar cleavage. Local warping and kinking of the S_1 cleavage occurs either as a result of a separate deformational event or as a late-stage progressive D_1 event. Near the McKenzie Gulch Fault and the north-striking subsidiary faults in the centre part of the map area, the F_1 folds become tighter and more chaotic in orientation due to the increased strain near the faults. East of the McKenzie Gulch Fault the carbonate rocks of the Matapédia Group and the Upsalquitch Formation have absorbed the bulk of the strain as indicated by tight to isoclinal folds and the development of a strong solution cleavage within the Matapédia Group. Dextral-transcurrent faults associated with D_1 (Acadian regional D_2) control the emplacement of intrusive rocks in the map area, as evidenced by their proximity to and parallelism to the faults.

GEOPHYSICAL PARAMETERS

A high-resolution, multiparameter airborne geophysical survey (Restigouche Project Phase I) was flown over the area in 1998, and included magnetic, electromagnetic and radiometric surveying (Geological Survey of Canada 1998a, 1998b). The geophysical data are providing useful additional information regarding both the surface extent of the newly defined units as well as highlighting the more interesting areas for mineral resource potential.

Magnetics

The most significant total field magnetic anomaly in the area lies in the central part of the map within the Grog Brook Group (Geological Survey of Canada 1998b). It measures approximately 9 x 5 km with approximate amplitude of 400 nt (nanoteslas). While the exact source of the anomaly is uncertain, a number of causes can be postulated. The subjacent rocks to the Grog Brook Group are not exposed in the

map area and the anomaly may simply reflect the presence of a "basement high", presumably the Popelogan Terrane mafic and/or ultramafic rocks. An alternative explanation is the presence of a buried intrusion which may have either mafic or felsic affinity. The possibility of a mineralized felsic to intermediate stock is intriguing for economic reasons; for example, tonalites are associated with the nearby Legacy Cu-skarn deposit (Moore and Lentz 1996). A mafic intrusion is also possible in the area since it has been observed that mafic dykes are more common west of the McKenzie Gulch Fault and these dykes may be associated with a deep-seated mafic body. The notion of a mafic body at depth is given further merit when viewed in light of the stream-silt geochemistry released by Pronk and Friske (1999), which reported Ni values of up to 748 ppm. Field investigations over the anomaly have not identified regional rock alteration that should be present if the Grog Brook Group hosts a major intrusion. However, some fractures and cleavage surfaces contain very finely disseminated pyrrhotite and chalcopyrite, which may represent distal fluid migration from a mafic intrusion.

The first vertical derivative of the magnetic data highlights shallow-source magnetic features and is useful in tracing surface structures such as faults and folds and narrow dykes. The large north-trending subsidiary fault on the east side of the map area is clearly traceable by differences in magnetic intensity of the rocks east and west of the fault. The large "fish-tail" fold pattern is also well defined and has been sourced to a relatively continuous pyrrhotite-bearing (>1%) fine-grained sandstone bed in the transitional zone between the *carbonaceous shale unit* and the *sandstone-dominated unit*. The *sandstone-dominated unit* can be differentiated from the *mudstone-dominated unit* by the higher bulk magnetic susceptibility of the latter, and both units can be differentiated from the calcareous rocks of the Upsalquitch Formation and the Matapédia Group, which have bulk magnetic susceptibilities lower than the Grog Brook Group.

The felsic intrusive rocks show no magnetic response within the map area. However, there are a number of northwest-trending structures in the southeastern part of the area. These are interpreted as mafic dykes or recessive weathering lamprophyre dykes but attempts to locate the dykes in the field have been unsuccessful.

Electromagnetics

The most distinct airborne electromagnetic (AEM) anomalies occur as linear and convoluted map-scale anomalies generally trending north-northeast across the map area and are best observed on the Apparent Conductivity maps (Geological Survey of Canada 1998a). These conductivity anomalies have been sourced to the *carbonaceous shale unit*, which contains significantly more conductive carbonaceous and sulphidic material than the surrounding lithotypes. The "fish-tail" fold pattern is clearly defined by the AEM anomalies and flanks the largest magnetic vertical derivative anomaly throughout most of its length. The McKenzie Gulch Fault and a subparallel fault to the east are also traceable by the AEM data. The *mudstone-dominated unit* can be distinguished from the *sandstone-dominated unit* and the calcareous formations (Matapédia and Upsalquitch) because of the higher carbon content that occurs as millimetre scale laminae throughout the unit. The width of the anomalies commonly reflects the orientation of bedding within the carbonaceous shale with flatter bedding orientations producing broader responses.

The intrusive phases, whether mafic or felsic, have no electromagnetic expression in terms of conductivity contrast with their host rocks.

Radiometrics

The airborne radiometric data are presented as Thorium (equiv. Th in ppm), Potassium (K %), Uranium (equiv. U in ppm) and air absorbed dose rate maps (Geological Survey of Canada 1998a). The *mudstone-dominated unit* consistently displays higher values than the surrounding units on all four maps, typically 0.75 to 1.5 ppm higher in equivalent Th, 0.5 to 1.0 % higher in K, 0.5 to 0.8 higher in equivalent U and 5 to 10 nG/h (nanoGrays/hour, 1 Gray = 100 rad) higher with respect to the air absorbed dose rate. Presumably the fine grain size, density, increased carbon content and lack of calcareous lithotypes in the *mudstone-dominated unit* are responsible for the elevated values. The same trend is noted when comparing the Upsalquitch Formation with the Matapédia Group. The Upsalquitch Formation displays slightly higher Th, U and K values than do the Matapédia rocks, which is a function of the increased amount of terrigenous material incorporated into the Upsalquitch Formation. However, the trend is not everywhere apparent, making the contact difficult to determine in some areas.

The intrusive rocks are not detected by the radiometric survey, which is in contrast to the results of Giggie (1999) who noted strong positive magnetic anomalies and low thorium anomalies over the felsic intrusions in the Squaw Cap area. To date, the intrusions documented in this study are a maximum of 20 m thick, which is probably below the detection range of the survey given the radiometric contrasts between the dykes and their host rocks.

DISCUSSION AND CONCLUSION

Geological mapping in the east half of the Kedgwick (NTS 21 O/11) map area, in conjunction with Phase I of the Restigouche airborne geophysical survey, has been successful in subdividing the Grog Brook Group. Three as-yet-unnamed units are proposed: (1) the *mudstone-dominated unit*; (2) the *carbonaceous shale unit*; and (3) the *sandstone-dominated unit*, in ascending stratigraphic order. Formal naming will be undertaken when areal extent and type locations can be determined. The distribution of the units suggests initial low energy deposition on a continental slope under dysaerobic conditions (*mudstone-dominated unit*), followed by deposition under anaerobic (anoxic) conditions (*carbonaceous shale unit*), and culminating in channel-fill and overbank sequences deposited in an active basin under dysaerobic to aerobic conditions. Several scenarios can explain the distribution of the lithotypes observed, such as changing tectonic/environmental conditions producing a sea-level rise and fall and, in turn, producing changes in accommodation space and sediment input. Alternatively, the basin may have been "redox-stratified" such that conditions in the middle depths were anoxic whereas conditions in the upper and lower depths were slightly more oxidizing, producing a "bathtub ring" of carbonaceous shale, a phenomena documented elsewhere in the world (Klein 1991). Further comparison with interpreted palaeoenvironmental conditions elsewhere in the Aroostook–Percé Anticlinorium is required to better define the depositional model.

The Pat Brook beds are not assigned to the Grog Brook Group, although the formation appears to be at the same stratigraphic level, because initial observations suggest that the provenance of the Pat Brook rocks is more closely related to the Honorat Group. The poor exposure in the area precludes detailed investigation of the contact relationships with both the Popelogan Formation and the Matapédia Group. Procurement of trace-element chemistry for comparison with the Grog Brook and Honorat groups will assist in elucidating this problem.

The large total field magnetic anomaly in the centre part of the map area reflects a "basement rock" source or a subjacent intrusion that may have economic significance since the anomaly is spatially related to Ni and Cu stream-silt anomalies. Minor amounts of pyrrhotite and chalcopyrite occur along cleavage planes and local fractures adjacent to the anomaly but the host rocks are otherwise unaltered.

Airborne geophysical surveys have provided information crucial to the subdivision of the Grog Brook Group. The *carbonaceous shale unit* is readily traceable via airborne electromagnetics, which greatly assisted in outlining the limits of the unit. Further work will better elucidate the relationship of these rocks to the Ni and Cu stream-silt anomalies in the central part of the study area. The radiometric data are effective in distinguishing the *sandstone-dominated unit* and the carbonate-bearing formations from the *mudstone-dominated unit*. Limited delineation of the Upsalquitch Formation from the Matapédia Group is possible.

ACKNOWLEDGEMENTS

The author wishes to thank Steve McCutcheon for his training in the ways of sedimentology and the scientific method; a work still in progress. Additional thanks to Dave Lentz and Reg Wilson for many useful geological wanderings and to Phil Evans and Reg Wilson for much needed advice on figures. Also thanks to John Langton for explaining the intricacies of CARIS©. Reviews by Reg Wilson and Steve McCutcheon improved the manuscript.

REFERENCES

ALCOCK, F.J. 1935. Geology of Chaleur Bay Region. Geological Survey of Canada, Memoir 183.

ARTHUR, M.A. and SAGEMAN, B.B. 1994. Marine black shales: depositional mechanisms and environments of ancient deposits. Annual Review, Earth and Planetary Sciences, **22**: 499–551.

BOURQUE, P.-A., BRISEBOIS, D. and MALO, M. 1995. Gaspé Belt. *In* Chapter 4 of Geology of the Appalachian/ Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, No. 6, pp. 316–351.

FRASER, D.C. 1969. Assessment work report; Burntland area aeromagnetic survey, Restigouche County, New Brunswick for Keevil Mining Group Limited by Geophysical engineering & Surveys Limited. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471929.

GIGGIE, K. 1998. Geology of central Restigouche County (NTS 21 O/10, 11, 14, 15 and 16W). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-40. [Scale: 1:100 00]

GIGGIE, K.V. 1999. Ground follow-up to the multi-sensor airborne geophysical survey in central Restigouche County, New Brunswick: results and interpretation. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-9, 41p.

GEOLOGICAL SURVEY OF CANADA. 1998a. Magnetic first vertical derivative map, Kedgwick, New Brunswick; NTS 21 O/11. Geological Survey of Canada, Open File 3519. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-2A. [Scale: 1:50 000]. Also, Plate 98-2B (map of apparent conductivity, 4433 Hz-CP); Plate 98-2C (air absorbed dose rate map); Plate 98-2D (potassium map); Plate 98-2E (uranium map, eU); Plate 98-2F (thorium map, eTh); Plate 98-2G (thorium/potassium map, eTh/K).

GEOLOGICAL SURVEY OF CANADA. 1998b. Magnetic anomaly map (residual total field), Kedgwick, New Brunswick; NTS 21 O/11. Geological Survey of Canada, Open File 3621. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-2H. [Scale: 1:50 000]

HAMILTON-SMITH, T. 1970. Stratigraphy and structure of Ordovician and Silurian rocks of the Siegas area, New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigation No. 12, 55 p.

IRRINKI, R.R. 1990. Geology of the Charlo area; Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources Division, Report of Investigation 24, 118 p.

KLEIN, G. DE V. 1991. Basin sedimentology and stratigraphy—the basin fill. *In* Sedimentary and Diagenetic Mineral Deposits: A Basin Analysis Approach to Exploration. *Edited by* E.R. Force, J.J. Eidel, and J.B. Maynard. Reviews in Economic Geology, **5**: 51–89.

MALO, M. 1988. Stratigraphy of the Aroostook–Percé Anticlinorium in the Gaspé Peninsula, Québec. Canadian Journal of Earth Sciences, **25**: 893–908.

MALO, M. and BOURQUE, P.-A. 1993. Timing of the deformation events from Late Ordovician to Mid-Devonian in the Gaspé Peninsula. *In* The Acadian Orogeny: Recent Studies in New England, Maritime Canada and the Allochthonous Foreland. *Edited by* D.C. Roy, and J.W. Skehan. Geological Society of America, Special Paper 275, pp. 101–122.

MOORE, C.E. and LENTZ, D. R. 1996. Copper-skarn-associated felsic intrusive rocks in the McKenzie Gulch area (NTS 21 O/10), Restigouche County, New Brunswick. *In* Current Research1995. *Edited by* B. M. W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 96-1, pp.121–153.

PHILPOTT, G.R. 1988. Precious-metal and geological investigation of the Charlo River area, New Brunswick. *In* Thirteenth Annual Review of Activities, project résumés, 1988. *Edited by* S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 88-2, 191 p.

PICKERILL, R.K. 1980. Phanerozoic flysch trace fossil diversity—observations based on an Ordovician flysch ichnofauna from the Aroostook–Matapédia Carbonate Belt of northern New Brunswick. Canadian Journal of Earth Sciences, **17**: 1259–1270.

PRONK, A.G. and FRISKE, P.W.B. 1999. Cu, Ni and Co content of stream-sediment samples for the Kedgwick map area (NTS 21 O/11), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-13B [scale: 1:50 000]

SKIDMORE, W.B. 1965. Honorat–Reboul area, Bonaventure County. Quebec Department of Natural Resources, Geological Report 107.

ST. PETER, C. 1978. Geology of parts of Restigouche, Victoria, and Madawaska counties, northwestern New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigation 17, 69 p.

VAN STAAL, C.R. and DE ROO, J.A. 1995. Mid-Paleozoic tectonic evolution of the Appalachian Central Mobile Belt in northern New Brunswick, Canada: collision, extensional collapse and dextral transpression. *In* Current Perspectives in the Appalachian–Caledonian Orogen. *Edited by* J.P. Hibbard, C.R. van Staal, and P.A. Cawood. Geological Association of Canada, Special Paper 41, pp. 367–389.

WILSON, R.A. 1990. Tobique project—Victoria, Restigouche, and Northumberland counties, New Brunswick. *In* Project summaries for 1989, Fourteenth Annual Review of Activities. Edited by S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 89-2, 246 p.

WILSON, R.A. 2000. Geology of the Popelogan Lake–Lost Pine Lake area (NTS 21 O/15a and b), Restigouche County, New Brunswick. *In* Current Research 1999. (this volume)

A PRELIMINARY SEQUENCE STRATIGRAPHY OF THE HORTON GROUP, SOUTHEASTERN NEW BRUNSWICK: INTERPRETATION OF THE DAWSON SETTLEMENT MEMBER OF THE CARBONIFEROUS ALBERT FORMATION, SHELL ALBERT MINES #4 WELL

Dave Keighley
Geology Department, Saint Mary's University, Halifax, Nova Scotia, CANADA B3H 3C3
(e-mail: keighley@nbnet.nb.ca)

KEIGHLEY, D. 2000. A preliminary sequence stratigraphy of the Horton Group, southeastern New Brunswick: interpretation of the Dawson Settlement Member of the Carboniferous Albert Formation, Shell Albert Mines #4 well. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 17–29.

Strata from the Dawson Settlement Member of the Albert Formation (Carboniferous) in the recently cored Shell Albert Mines #4 well, Moncton Subbasin, southeastern New Brunswick, are being investigated with the aim of establishing a sequence stratigraphy. Albert Formation strata are considered typical of an early, sediment-starved stage of a low resolution, tectonically driven sequence that formed in a climatically 'balanced' to 'overfilled' intermontane basin. At higher resolution, the working model proposes that thick, potentially high relief, fan-deltas and terraces were forming at the basin margin during the prolonged pluvials while, elsewhere in the basin, laminated mudstones were being formed in a quiet-water, probably deep, open lake. During climatic dry spells, lake level dropped, producing a sequence boundary. The marginal aprons of sediment were partially reworked out toward the basin centre, forming, at the well locality, shallow lacustrine bars of medium- and finer-grained sandstone and relatively low relief, prograding fan deltas of pebbly sandstone (including subaerially exposed, muddy delta floodplain topsets). These prograding deposits might have formed either in a closed basin setting during the early stages of renewed relative lake-level rise ('lowstand' deposits), or when the lake had already transgressed to a temporary threshold and was spilling across a sill into another part of the basin or an adjacent basin. Overlying the delta topsets are additional lacustrine sandstones and mudstones of a transgressional nature, formed as lake level continued to rise.

On est en train d'étudier des strates du membre Dawson Settlement de la Formation d'Albert (Carbonifère) dans le puits n° 4 d'Albert Mines récemment foré par Shell à l'intérieur du sous-bassin de Moncton, dans le Sud-Est du Nouveau-Brunswick, en vue d'établir une stratigraphie séquentielle. Les strates de la Formation d'Albert sont considérées comme des éléments typiques d'un stade précoce de faible remplissage sédimentaire d'une séquence d'origine tectonique à basse résolution qui s'est formée dans un bassin intramontagneux allant de climatiquement «équilibré» à «débordant». À une résolution supérieure, le modèle d'étude suppose que des terrasses et des deltas alluviaux au relief pouvant être élevé se sont formés à la limite du bassin au cours des périodes pluviaires prolongées pendant qu'ailleurs à l'intérieur du bassin, des mudstones feuilletés se formaient dans un lac ouvert aux eaux calmes et vraisemblablement profond. Pendant les périodes de sécheresse climatique, le niveau du lac a chuté et produit une limite de séquence. Les plaines d'épandage limitrophes ont partiellement été repoussées vers le centre du bassin, formant à l'emplacement du puits des bancs lacustres peu profonds de grès à grain moyen et grain plus fin

ainsi que des deltas alluviaux caillouteux au relief relativement émoussé en progression vers la mer (y compris des lits sommitaux de plaines inondables deltaïques boueuses présentant un affleurement subaérien). Ces accrétions littorales pourraient s'être formées soit dans un milieu de bassin fermé au cours des stades initiaux du relèvement relatif du niveau du lac (dépôts «de bas niveau»), soit après que le lac avait déjà atteint un seuil limite temporaire et débordait par un seuil dans une autre partie du bassin ou un bassin adjacent. D'autres mudstones et grès lacustres de nature discordante s'étant formés au fur et à mesure que le niveau du lac a continué à monter recouvrent les lits sommitaux deltaïques.

INTRODUCTION

New data from the recent Shell Canada drilling program in the Horton Group of the Moncton Subbasin, southeastern New Brunswick (Figure 1), provides an opportunity to increase our understanding of the Albert and associated formations in the southern part of the subbasin. Existing correlations and models of sandbody and oil shale distribution are based on lithostratigraphy and facies modelling. This work attempts to enhance these existing interpretations by applying a sequence stratigraphy to the formations. A particular focus is the succession below the major Albert Formation oil shale zone, which is most directly comparable with strata being investigated in the analogous (Greiner 1962) Uinta Basin of Utah, U.S.A., where a lacustrine sequence stratigraphy is also being established (Keighley *et al.* 1999, 2000). Sequence-stratigraphic terms, as applied herein, follow the definitions of Van Wagoner *et al.* (1990).

LITHOSTRATIGRAPHY AND LITHOFACIES

The lithostratigraphy of the Moncton Subbasin was most recently reviewed by St. Peter (1992, 1993) and St. Peter and Johnson (1997) who identified three, unconformity bounded, Carboniferous allocycles (Figure 2). The lowermost (primarily Tournaisian), Horton Group succession comprises two, red to grey, conglomerate-dominated intervals (a basal Memramcook Formation and an upper Weldon Formation) enclosing a shale-dominated interval (Albert Formation). The Albert Formation itself is subdivided on the basis of the predominance of oil shales, and it is the strata beneath the main oil shales (Frederick Brook Member), attributable to the Dawson Settlement Member, that has been investigated in this study.

A wide variety of lithofacies have been recorded by previous workers. Greiner (1962), Howie (1968), and Pickerill and Carter (1980), for example, have detailed the alluvial fan and fluvio-deltaic facies, while algal swamp, shoreface, carbonate mudflat, and shallow lacustrine, evaporitic lithofacies were first detailed by Carter and Pickerill (1985). Most comment, however, has been reserved for the oil shales (e.g., Norman 1932; Macauley *et al.* 1984; Smith and Gibling 1987; and Chowdhury *et al.* 1991).

The lithofacies model projects a humid tropical intermontane setting with alluvial fans and fluvio-deltaic deposits enclosing lacustrine strata in at least two structurally discrete subbasins. Foley (1989) identifies the northerly Petitcodiac Subbasin and southeasterly Hillsborough Subbasin as components of the Moncton Subbasin. Relatively deep lakes (tens of metres) are thought to have persisted in the southeast with more transient lakes elsewhere (Chowdhury and Noble 1992). However, most authors have noted that lake area and depth fluctuated due to numerous lake transgressions and regressions. Carter and Pickerill (1985) also envisioned the lake evolving with time from a predominantly closed lake to an open one.

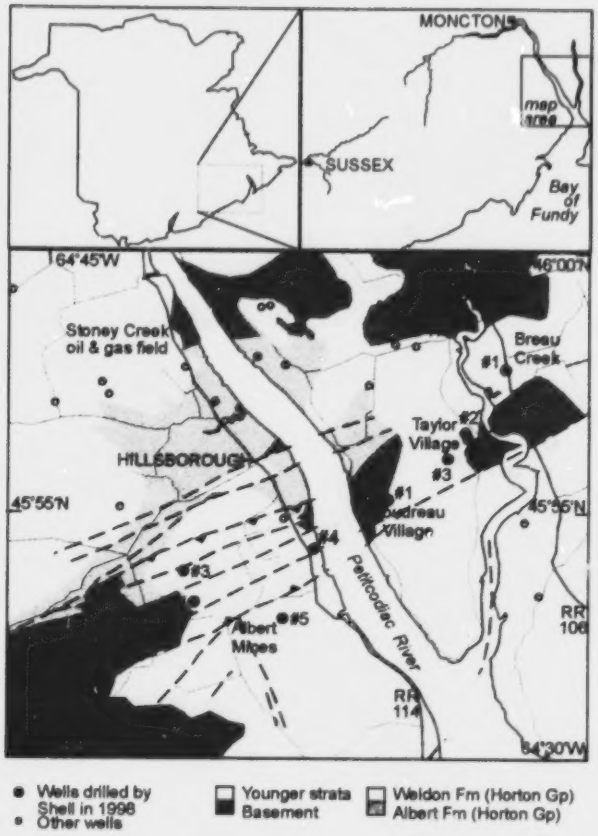


Figure 1. Location of, and general geology adjacent to, Shell Albert Mines #4 well (after St. Peter and Johnson 1997).

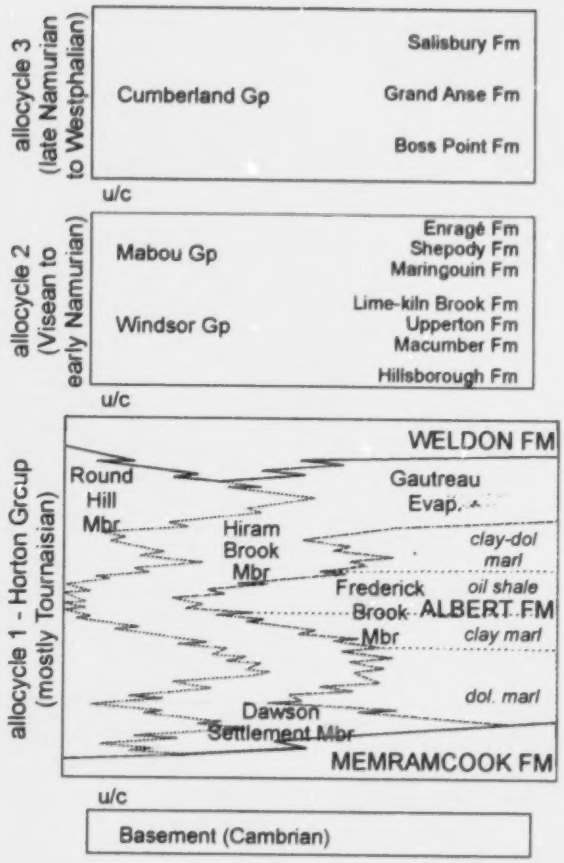


Figure 2. Stratigraphy of the Moncton Subbasin (after St. Peter 1992, 1993).

DAWSON SETTLEMENT MEMBER LITHOFACIES, SHELL ALBERT MINES #4

Shell Albert Mines #4 was cored from the surface to a total depth of 762.3 m. The Dawson Settlement Member (641.5 m or 679.2 m to total depth, depending on the pick) has only been partly penetrated by this well, but has been logged in detail (Figure 3). The logged interval comprises thick, dark grey, variably calcareous/dolomitic, distinct to diffusely laminated shales, readily interpreted as lacustrine facies deposited below wave base, and a major sandstone-dominated interval between approximately 730.5 and 679.0 m.

Shale and mudstone interbeds occur within this sandstone-dominated interval. They are parallel laminated at approximately 729.0, and at 687.0 m to approximately 685.0 m, and are interpreted as quiet-water lacustrine deposits. Note that interpretation of 'deep' or 'shallow', 'nearshore' to 'offshore' quiet-water

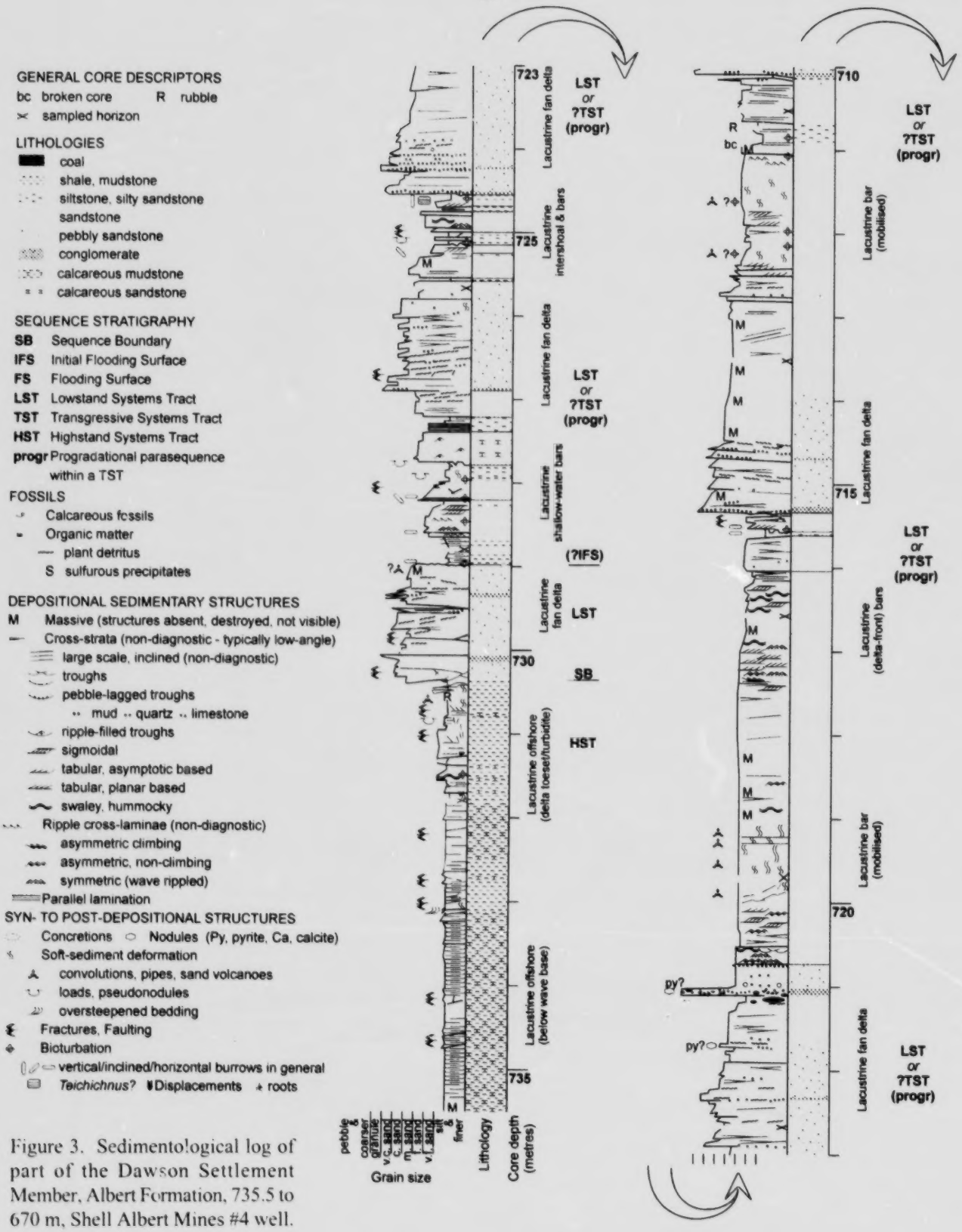
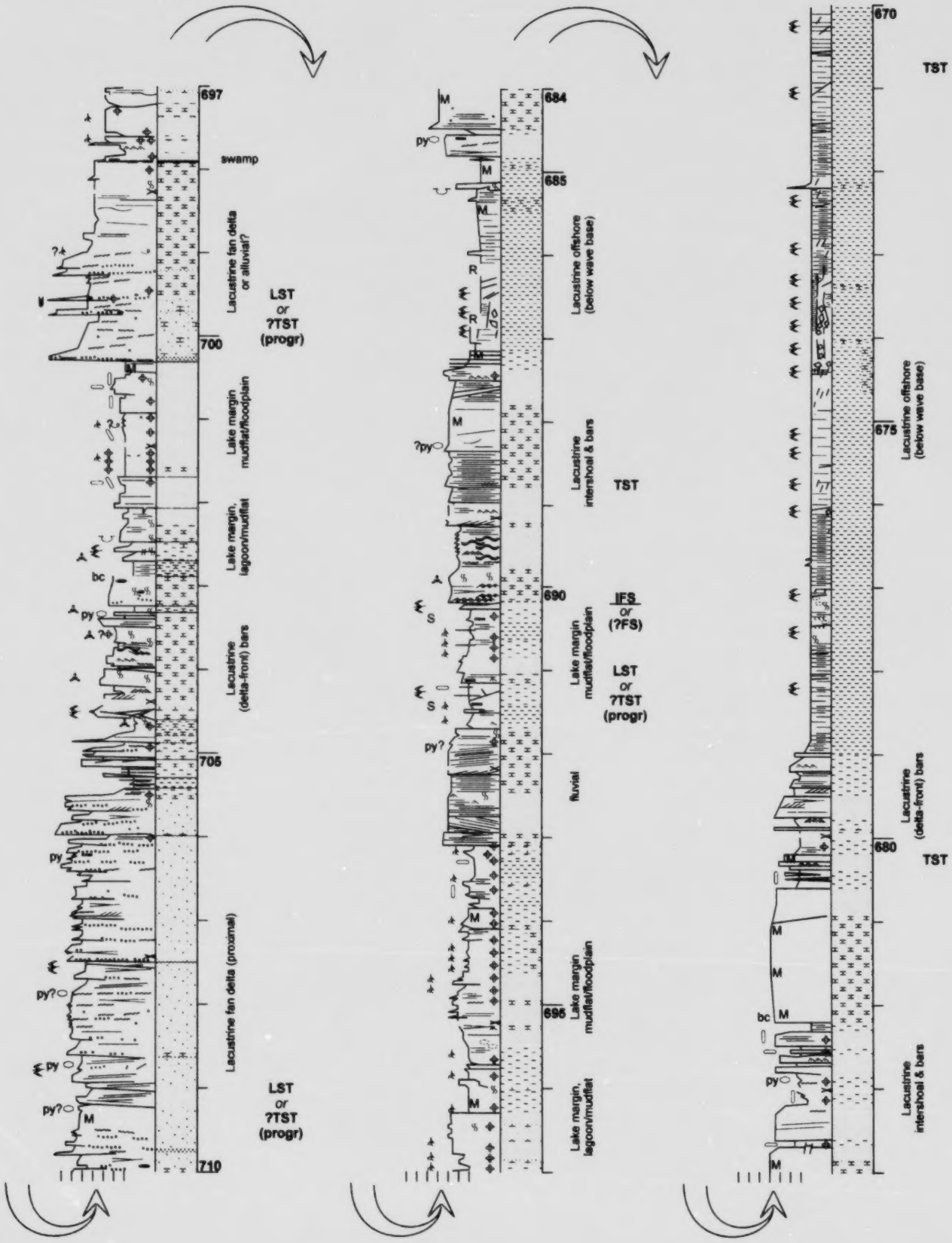


Figure 3. Sedimentological log of part of the Dawson Settlement Member, Albert Formation, 735.5 to 670 m, Shell Albert Mines #4 well.


697
swamp
Lacustrine fan delta or alluvial?
LST or ?TST (progr)
700
Lake margin mudflat/floodplain
Lake margin, lagoon/mudflat
Lacustrine (delta-front) bars
705
Lacustrine fan delta (proximal)
LST or ?TST (progr)
710
684
Lacustrine offshore (below wave base)
685
Lacustrine intershoal & bars
TST
690
IFS or (?FS)
Lake margin mudflat/floodplain
LST or ?TST (progr)
fluvial
695
Lake margin mudflat/floodplain
Lake margin, lagoon/mudflat
670
TST
Lacustrine offshore (below wave base)
675
Lacustrine (delta-front) bars
680
TST
Lacustrine intershoal & bars

settings requires much more detailed investigation of facies associations, as previously inferred by Pickerill (1992). In contrast, the siltstones, mudstones, and associated sandstones between 704.0 and 700.3 m, and 697.9 and 690.2 m are bioturbated, typically massive, and retain evidence of root casts (rhizoliths). These strata are considered indicative of subaerial exposure, such as on a vegetated delta floodplain or lake margin flats where there was incipient soil development.

The coarse-grained clastics between 730.5 m and 679.0 m are variably sandy, pebbly, or conglomeratic, are variably calcite cemented, and are locally oil stained. Well-sorted, wave rippled to small-scale swaley, medium- to very-fine-grained sandstone (e.g., 728.7–727.2 m, 720.75–720.0 m, 717.5–715.4 m) and any intervening soft-sediment deformed (e.g., dewatering pipes between 720.0 and 719.0m) sandstones are confidently identified as lacustrine facies. The ripples and swales indicate deposition above storm wave-base while the dewatering pipes indicate rapid deposition and subsequent sediment liquefaction. The interpretation of other sandstones is less certain. Sandstones at 693.1 to 691.7 m, and 689.25 to 687.55 m are medium-grained, distinctly well sorted, and cross-stratified. Particularly in the case of the lower sandstone, its occurrence within a rooted interval might suggest deposition within a small fluvial channel. Pebbly sandstone and conglomeratic beds are more diffusely stratified by pebbly and/or carbonaceous lags, or graded strata. Beds may be between 0.5 and 2.0 m thick and fine upward. Some (e.g., 727.0–725.0 m) may grade upward eventually into the lacustrine sandstone facies and, because of the lack of any subaerial indicators interbedded with the conglomerates, they are herein speculated to be the subaqueous part of a fan delta or Gilbert Delta. A similar interpretation is given to the sandstones incompletely cored at the base of the well (762.3–756.0 m). Elsewhere, similar associations have led St. Peter (1992, 1993) also to suggest that at least some of the Albert Formation conglomerates are lacustrine, but diagnostic evidence is lacking.

LOW-RESOLUTION SEQUENCE STRATIGRAPHY OF LACUSTRINE BASINS

Low-resolution (i.e., relatively long duration) models of lacustrine basins indicate that very different sequences form dependent upon the interplay of climate and the stage of tectonic evolution of the host basin. For any tectonic, hydrologically closed basin, subsidence or basin-margin uplift initially produces accommodation space at a volumetric rate that is greater than the volume of sediment supplied to the basin in a particular time period. The succession is considered sediment starved (stages 1 and 2 of Lambiase 1990; Schlische and Olsen 1990), and thick successions of fines and/or precipitates form over a basal coarse clastic unit. Subsequently, accommodation space is filled as a result of reduced subsidence/uplift and/or increased sediment supply through river capture increasing drainage areas and, or, infilling of adjacent basins resulting in bypass of sediment to the basin in question (stages 3 and 4 of Lambiase 1990). Coarser grained sediments are deposited until the basin is finally infilled. Such a low-resolution sequence is present in the Moncton Subbasin as St. Peter's (1993) Horton Group or 'Allocycle 1' (Figures 2, 4A and 4B). The Dawson Settlement Member, at the base of the predominantly lacustrine Albert Formation, is classified within stage 2 of this low-resolution tectonic sequence.

Base level in terrestrial basins is defined by lake level and/or the watertable (Gore 1989). If the lake is closed, slight changes in precipitation (inputs) and evaporation (outputs) can change base level even on an annual basis. In contrast, if a lake expands to its threshold and there is drainage spillover at the basin sill, further lake base-level rise is impossible (unless the spillover is into another basin lake that itself is

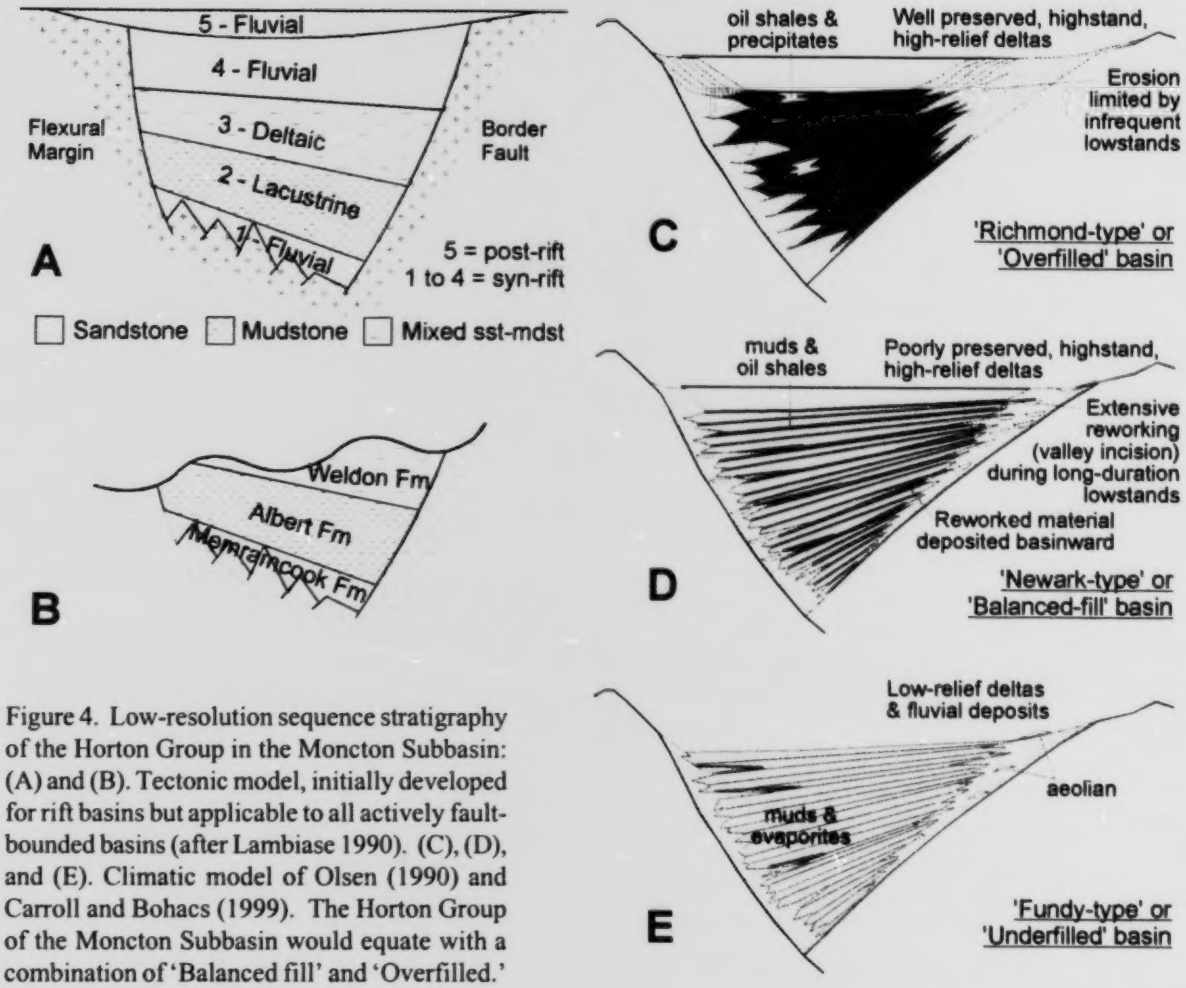


Figure 4. Low-resolution sequence stratigraphy of the Horton Group in the Moncton Subbasin: (A) and (B). Tectonic model, initially developed for rift basins but applicable to all actively fault-bounded basins (after Lambiase 1990). (C), (D), and (E). Climatic model of Olsen (1990) and Carroll and Bohacs (1999). The Horton Group of the Moncton Subbasin would equate with a combination of 'Balanced fill' and 'Overfilled.'

able to fill to the elevation of the sill and the two lakes merge). Regardless of further increases in inputs, the lake is balanced by increased spillover outputs. While the water budget remains balanced, the base level remains stable. Through a basin's geological lifetime, its contained lake may vary from hydrologically open to closed: the duration of each has been identified as exerting a primary control on the sedimentary composition and architecture of the basin fill (Figures 4C to 4E, and Olsen 1990; Scholz *et al.* 1998; Carroll and Bohacs 1999; Keighley *et al.* 1999, 2000). If the basin existed under a primarily wet climate (overfilled), fluvial-lacustrine facies dominated. Clastic sediment would have accumulated around the basin margins forming terraced aprons and highstand deltas, which may have been of high relief if the structurally controlled sill permitted deep lakes to form. Progradational aprons developed during periods of tectonic quiescence; aggradational and basin-marginal aprons developed with continuous subsidence (hence progradation is preferred during later stages of basin fill). If the basin existed under a climate that was periodically drier (balanced fill), the base level could have dropped at these times to a variable elevation well below threshold. The result would have been the formation of fluctuating profundal facies and the partial to complete incision and reworking of the apron deposits (depending on the duration of the dry period). For a basin that existed under a primarily dry climate (underfilled), threshold may never have been attained, no aprons ever having been developed, and the fill would have been typified by

evaporitic, alluvial fan, and aeolian strata. A scenario between balanced and overfilled for lower Albert Formation lakes (balanced and underfilled for uppermost Albert Formation) is indicated by existing facies interpretations of earlier noted authors.

In overfilled basins, relative lake-level rise and generation of accommodation space will be primarily driven by tectonics. Elsewhere, climatic cycles will drive fluctuations in lake-level on numerous time scales and magnitudes. Relative falls in lake level and resultant facies shifts are likely for some part of each order of cycle, producing hiatuses significant at that scale of resolution. Although sequences may therefore be stacked within lower order (lower resolution) sequences, the commonly used hierarchy that reflects global sea-level curves is not equivalent or appropriate for lacustrine basins. Base level fluctuates much more rapidly and basin life span is much shorter, typically a maximum of a few million years.

HIGH-RESOLUTION SEQUENCE STRATIGRAPHY OF THE ALBERT MINES #4 WELL

The detail and confidence that can be applied to a high-resolution sequence stratigraphy is dependent on a synthesis of wide-ranging geological data that can include biostratigraphy and radiometric dating as time constraints, and outcrop correlation and seismic cross-sections for the three-dimensional constraint of key horizons and surfaces. Sequence stratigraphy is also a second-stage interpretation dependent upon prior lithofacies analysis and, as illustrated in the core description previously, the precision with which a rock unit can be provided with a facies interpretation is variable, particularly in core. This means that the preliminary interpretation provided below is model driven and based on the limited high-resolution sequence-stratigraphic work undertaken in lacustrine basins (e.g., Shanley and McCabe 1994, and works reviewed therein; Oviatt *et al.* 1994; Dam *et al.* 1995; Keighley *et al.* 1999).

The thick mudstones that enclose the major sandstone interval are considered to represent the most distal facies present in the succession, and so their presence suggests occasions when the lake is considered to have been at its deepest and coarse clastics were being deposited only toward the basin margin. The intervening sandstones, in this respect, must represent a period when coarse clastic sedimentation was able to advance out into the basin. Facies interpretations indicate that the advance was of delta front/ nearshore and delta top/mudflat deposits. This advance could have been the result of autocyclic delta-mouth switching, or allocyclic increase in sediment supply such as by river capture in the hinterland, lake-level stillstand and/or relative lake-level fall and rise. However, if the delta advanced simply due to increased sediment supply or a lake-level stillstand, it would be expected that the transition from laminated shale to conglomerate would be observed as a gradual coarsening upward, as the delta slowly built its way out into the basin. The same would be true if an existing delta switched its mouth to this locality, unless the avulsion was nearby (in which case evidence of a delta nearby would again be expected prior to the introduction of such coarse clastics). The sharp contact between the shale and overlying pebbly sandstone at 730.4 m is interpreted, instead, to mark a major drop in lake level. The lowered storm wave-base would then result in the erosion of the lake floor and subsequent deposition of shallow lake and subaerial deposits (a sequence boundary, cf. Dam and Surlyk 1992).

At this high level of resolution, subaerially influenced, fine-grained deposits between approx. 702.0 and 690.0 m are overlain by sandstones containing a more lacustrine aspect (690.2–689.25 m) and fines of lacustrine quiet-water origin (approximately 687.5–685.0 m, and then the main shales above 679.0 m).

This would indicate that lake level was rising considerably and that this interval would be part of a Transgressive Systems Tract (the overlying Maximum Flooding Surface being above the investigated interval at 641.5 m, marking the onset of the major oil-shale deposition).

The base of the Transgressive Systems Tract, defined by the initial significant flooding surface (or equivalent), is dependent upon what is considered 'significant.' Two potentially key surfaces are identified. The first is where there is a facies shift from rooted, delta-top strata at 690.2 m, to sandstones that include lacustrine bar deposits, and which give way upward to laminated quiet-water shales. If this were considered the key transgressive surface, the strata between it and the underlying sequence boundary (at 730.4 m) would be 'lowstand' deposits. Alternatively, the slightly irregular, sharp surface at 729.0 m can be interpreted as a ravinement surface formed by erosion of lake lowstand deposits (730.4–729.0 m) during an initial, rapid lake transgression that deposited the overlying, greater than 0.5 m thick, laminated mudstones at 729.0 to 728.65 m. A similar ravinement surface has been noted by Dam and Surlyk (1992).

Hypothesis #1

The entire coarsening-upward succession of individually fining-upward beds of nearshore sandstones and fan-delta conglomeratic sandstones (728.65–705.5 m) is indicative of progradational parasequences. The presence of rooted mudstones and perhaps small fluvial channel sandstones above 705.5 m would further indicate the progradational extension of delta topsets to this locality. If the transgressive surface is taken at 690.2 m, the entire progradational succession represents deposition under the initial slow rise in base level. In this sense, the presence of a progradational package invites comparison with the Lowstand Prograding Complex of a classic Late Lowstand Systems Tract that also requires the identification of an underlying 'Exxon type 1' sequence boundary (Van Wagoner *et al.* 1990). Such tracts and sequence boundaries are typical of a continental shelf setting. Marginal aprons hypothesized to form at lake highstand might represent the equivalent of a shelf, with subsequent base-level fall resulting in their gradual incision and formation of the 'type 1'-equivalent boundary. However, until the study is extended to three dimensions, the presence of an apron and a 'type 1'-equivalent boundary, as well as the assignment of the transgressive surface, is speculative.

Hypothesis #2

Alternatively, if the transgressive surface is taken at 729.0 m, only the pebbly sandstone bed from 730.4 to 729.0 m represents lowstand deposits, yet it differs from overlying pebbly sandstones only in having more macerated organic fragments. The progradational package from 728.65 to 690.2 m would represent a stage when base-level rise slowed significantly or even was stable, the lake having expanded to a temporary maximum. A temporary lake maximum would exist when a lake reaches the elevation of a sill and spills into another part of the basin or into the adjacent basin. The thickness of the aqueous part of the progradational package, approximately 23 m, would be roughly equivalent to lake depth at this locality during deposition of the package. This threshold level and 'open' condition would be maintained until lakes in other (parts of the) basin(s) achieved the same elevation and merged to permit deepening toward a greater maximum. The merging of lakes prior to deposition of thick oil shales has been noted for the Uinta and adjacent Piceance Creek basins in Utah (e.g., Young 1995).

SUMMARY

A sequence-stratigraphic study of the Horton Group of the Moncton Subbasin, southeastern New Brunswick, has been initiated with the examination of the Dawson Settlement Member of the Albert Formation in the recently cored Shell Albert Mines #4 well. Laminated shales and mudstones deposited in a quiet-water, probably deep, lacustrine setting enclose an interbedded sandstone–mudstone interval. The fines of this interbedded interval are considered the product of vegetated delta floodplain or lake-margin mudflat sedimentation. The well-sorted, wave rippled to small-scale, swaley sandstones are the product of lacustrine deposition above storm wave-base. Other well-sorted, cross-stratified sandstones may be the result of fluvial channel deposition. Pebbly to locally conglomeratic sandstones in the interbedded interval are less assuredly attributed to deposition in the subaqueous part of a fan delta or Gilbert Delta, as are the sandstones incompletely cored at the base of the well.

Albert Formation strata are considered typical of the early, sediment-starved stage of a low-resolution, tectonically driven sequence that formed in a climatically balanced to overfilled intermontane basin setting. At higher resolution, it is speculated that thick, potentially high relief, fan-deltas and terraces aggraded at the basin margin during times when a deep open lake persisted in the basin. During climatic dry spells, lake levels dropped, producing a sequence boundary. The marginal aprons of sediment were partially reworked out toward the basin centre to form 'lowstand' deposits above the sequence boundary. The reworked deposits may have formed prograding fan deltas (of relatively low relief) and bars in a shallow closed lake (true 'lowstand' deposits). Alternatively, the lake may have already started to transgress and have reached a temporary threshold where it was spilling over a sill into another (part of the) basin, the deposits representing a prograding parasequence associated with an early lake stillstand within the Transgressive Systems Tract.

This study is still in its early stages and the higher-resolution sequence stratigraphy presented should be viewed as working hypothesis to be reviewed following further data collection and analysis. However, whichever way the 'lowstand' deposits are viewed, they indicate that there was a climatic control on the expansion of coarse clastics toward the basin centre. Since climate controls are usually cyclic, the potential exists for the same succession identified between approximately 731.0 and 679.0 m to recur farther down in the succession (potentially the upper part of a similar succession is cored at the base of the well between 762.3 and 756.0 m). Also, since topsets are preserved, it suggests that the main cored sandstone will extend significantly further out toward the basin centre.

ACKNOWLEDGEMENTS

Ron Pickerill (University of New Brunswick) and Stephen Flint (University of Liverpool, England) are thanked for their critical reviews. Clint St. Peter and Malcolm McLeod (New Brunswick Department of Natural Resources and Energy) are thanked for discussions and logistic help.

REFERENCES

CARROLL, A.R., and BOHACS, K.M. 1999. Stratigraphic classification of ancient lakes: Balancing tectonic and climatic controls. Geology, **27**: 99–102.

CARTER, D.C., and PICKERILL, R.K. 1985. Algal swamp, marginal and shallow evaporitic lacustrine lithofacies from the late Devonian–early Carboniferous Albert Formation, southeastern New Brunswick, Canada. Maritime Sediments and Atlantic Geology, **21**: 69–86.

CHOWDHURY, A.H., and NOBLE, J.P.A. 1992. Porosity evolution in the Albert Formation of the Stoney Creek Oil and Gas Field, Moncton Subbasin, New Brunswick, Canada. American Association of Petroleum Geologists Bulletin, **76**: 1325–1343.

CHOWDHURY, A.H., FOWLER, M.G., and NOBLE, J.P.A. 1991. Petroleum geochemistry and petroleum geology of the Albert Formation, Moncton Subbasin, New Brunswick, Canada. Bulletin of Canadian Petroleum Geology, **39**: 315–331.

DAM G., and SURLYK, F. 1992. Forced regression in a large wave and storm dominated anoxic lake, Rhaetian-Sinemurian Kap Stewart Formation, East Greenland. Geology, **20**: 749–752.

DAM, G., SURLYK, F., MATHIESEN, A., and CHRISTIANSEN, F.G. 1995. Exploration significance of lacustreine forced regressions of the Rhaetian-Sinemurian Kap Stewart Formation, Jameson Land, east Greenland. *In* Sequence Stratigraphy on the Northwest European Margin. *Edited by* R.J. Steel. Proceedings of the Norwegian Petroleum Society Conference, 1–3rd February 1993, Stavanger. Norsk Petroleumsforening, Special Publication 5, pp. 75–96.

FOLEY, S.L. 1989. Geology of the Stoney Creek Oil and Gas Field, and its implication regarding the tectonic evolution of the eastern Moncton subbasin. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Geoscience Report 89-1, 77 p.

GORE, P.J.W. 1989. Toward a model for open- and closed-basin deposits in ancient lacustrine sequences: The Newark supergroup (Triassic–Jurassic), eastern North America. Palaeogeography, Palaeoclimatology, Palaeoecology, **70**: 29–51.

GREINER, H.R. 1962. Facies and sedimentary environments of Albert shale, New Brunswick. American Association of Petroleum Geologists Bulletin, **46**: 219–234.

HOWIE, R.D. 1968. Stoney Creek gas and oil field, New Brunswick. American Association of Petroleum Geologists, Memoir 9, v. 2, pp. 1819–1832.

KEIGHLEY, D., COLLINS, S., FLINT, S., and HOWELL, J. 1999. Reservoir-scale distribution of fluvial sandbodies in lacustrine closed basins, and some sequence-stratigraphic implications: Green River Formation, SW Uinta Basin, east-central Utah. American Association of Petroleum Geologists Annual Convention, San Antonio, U.S.A., April 1999, Abstracts Volume, p. A71.

KEIGHLEY, D., FLINT, S., and MOSCARIELLO, A. 2000. Sequence-stratigraphic interpretations of alluvial–lacustrine basins: Uinta Basin, Utah, as an analogue of the Moncton Basin, New Brunswick. Atlantic Geoscience Society Colloquium, Fredericton, New Brunswick, Canada, February 2000. Abstracts Volume.

LAMBIASE, J.J. 1990. A model for tectonic control of lacustrine stratigraphic sequences in continental rift basins. *In* Lacustrine Basin Exploration – Case Studies And Modern Analogs. *Edited by* B.J. Katz. American Association of Petroleum Geologists, Memoir 50, pp. 265–276.

MACAULEY, G., BALL, F.D., and POWELL, T.G. 1984. A review of the Carboniferous Albert Formation oil shales, New Brunswick. Bulletin of Canadian Petroleum Geology, **32**: 27–37.

NORMAN, G.W.H. 1932. Stratigraphy of the Stoney Creek oil and gas field, New Brunswick. Geological Survey of Canada, Economic Geology Series 9, pp. 167–173.

OLSEN, P.E. 1990. Tectonic, climatic, and biotic modulation of lacustrine ecosystems – Examples from Newark Supergroup of eastern North America. *In* Lacustrine Basin Exploration – Case Studies And Modern Analogs. Edited by B.J. Katz. American Association of Petroleum Geologists, Memoir 50, pp. 209–224.

OVIATT, C.G., MCCOY, W.D., and NASH, W.P. 1994. Sequence stratigraphy of lacustrine deposits: a Quaternary example from the Bonneville basin, Utah. Geological Society of America Bulletin, **106**: 133–144.

PICKERILL, R.K. 1992. Carboniferous nonmarine invertebrate ichnocoenoses from southern New Brunswick, eastern Canada. Ichnos, **2**: 21–35.

PICKERILL, R.K. and CARTER, D.C. 1980. Sedimentary facies and depositional history of the Albert Formation. New Brunswick Department of Natural Resources, Open File Report 80-3, 132 p.

SCHLISCHE, R.W., and OLSEN, P.E. 1990. Quantitative filling model for continental extensional basins with applications to early Mesozoic rifts of Eastern North America. Journal of Geology, **98**: 135–155.

SCHOLZ, C.A., MOORE, T.C., HUTCHINSON, D.R., GOLMSHTOK, A.J., KLITGORD, K.D., and KUROTCHKIN, A.G. 1998. Comparative sequence stratigraphy of low-latitude versus high-latitude lacustrine rift basins: seismic data examples from the East African and Baikal rifts. Palaeogeography, Palaeoclimatology, Palaeoecology, **140**: 401–420.

SHANLEY, K.W. and MCCABE, P.J. 1994. Perspectives on the sequence stratigraphy of continental strata. American Association of Petroleum Geologists Bulletin, **78**: 544–568.

SMITH, W.D., and GIBLING, M.R. 1987. Oil shale composition related to depositional setting: a case study from the Albert Formation, New Brunswick, Canada. Bulletin of Canadian Petroleum Geology, **35**: 469–487.

ST. PETER, C. 1992. Lithologic facies, seismic facies and strike-slip setting of the Lower Carboniferous alluvial/fluvial/lacustrine Albert Formation of New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Geoscience Report 92-2, 145 p.

ST. PETER, C. 1993. Maritimes Basin evolution: key geologic and seismic evidence from the Moncton Subbasin of New Brunswick. Atlantic Geology, **29**: 233–270.

ST. PETER, C., and JOHNSON, S.C. 1997. Carboniferous geology of the Hillsborough area (NTS 21 H/15), Albert and Westmorland Counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-8.

VAN WAGONER, J.C., MITCHUM, R.M., CAMPION, K.M., and RAHMANIAN, V.D. 1990. Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high resolution correlation of time and facies. American Association of Petroleum Geologists, Methods in Exploration Series, **7**: 55 p.

YOUNG, R.G. 1995. Stratigraphy of Green River Formation in Piceance Creek Basin, Colorado. *In* The Green River Formation in Piceance Creek and Eastern Uinta Basins Field Trip. *Edited by* W.R. Averett. Grand Junction Geological Society, Grand Junction, Colorado, pp. 1–13.

LATE-GLACIAL (YOUNGER DRYAS) COLEOPTERA FROM SAINT JOHN, NEW BRUNSWICK (NTS 21 G/1) ‡‡

Randall F. Miller
Steinhammer Palaeontology Laboratory, New Brunswick Museum,
277 Douglas Avenue, Saint John, New Brunswick CANADA E2K 1E5 (e-mail: millerrf@nb.aibn.com)

MILLER, R.F. 2000. Late-glacial (Younger Dryas) Coleoptera from Saint John, New Brunswick (NTS 21 G/1). *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 31–38.

Fossil Coleoptera (beetles) from Quaternary deposits are used to reconstruct past environments and as proxy indicators of palaeotemperatures. Two sites in New Brunswick, Todd Mountain and Sand Cove Road, provide the only known records of late-glacial Coleoptera in the province. The Sand Cove Road locality in Saint John is a Younger Dryas age buried organic deposit dominated by herb and shrub pollen. Although small, the Coleoptera assemblage includes one indicator that allows comparison with other sites in the Maritimes Region. *Olophrum boreale*, a staphylinid beetle that occurs in the modern northern boreal forest, is found at Sand Cove Road. *O. boreale* is relatively abundant in Younger Dryas sites on Cape Breton Island where it has been interpreted as an indicator of climatic deterioration during the Younger Dryas chronozone when mean July temperatures may have dropped more than 5°C.

Les coléoptères fossilisés (barbeaux) trouvés dans les dépôts du quaternaire sont utiles aux paléontologues, car ils les aident à reconstituer des habitats anciens et à donner une indication de substitution des paléotempératures. Les deux seuls endroits connus où subsistent des traces de coléoptères de la fin de la période glaciaire au Nouveau-Brunswick sont la localité de Sand Cove Road, près de Saint-Jean, et Todd Mountain. Sand Cove Road, près de Saint-Jean, est un dépôt organique de pollen herbacé et arbustif qui remonte à la période plus récente Dryas. Bien qu'ils soient de taille réduite, ces vestiges de coléoptères comprennent un indicateur qui permet d'établir une comparaison avec d'autres vestiges ailleurs dans les Maritimes. L'insecte de la variété *Olophrum boreale*, un barbeau de la famille des staphynilidés présent dans la forêt boréale actuelle du nord, se retrouve sur le site de Sand Cove Road. L'espèce *O. boreale* est assez abondante sur les sites de la période plus récente Dryas de l'île du Cap-Breton. Sa présence en ces lieux a permis de rendre compte d'une détérioration climatique survenue au cours de cette période, au moment où les températures moyennes de juillet ont pu chuter de plus de 5 °C.

INTRODUCTION

The late-glacial environment of the Maritimes Region of eastern Canada has been investigated in detail, especially in relation to the Younger Dryas event (Mott *et al.* 1986; Stea and Mott 1989; Walker *et al.* 1991; Mott and Stea 1993; Mayle *et al.* 1993a, b; Wilson *et al.* 1993; Cwynar *et al.* 1994; Mott 1994; Mayle and Cwynar 1995; Stea and Mott 1998; Miller 1996; 1997a, b; Miller and Elias 2000). Data gathered from lake sediments and buried organic sites in Nova Scotia and New Brunswick provide

‡‡ New Brunswick Museum ordinary budget and National Geographic Society Research Grant 4588-91.

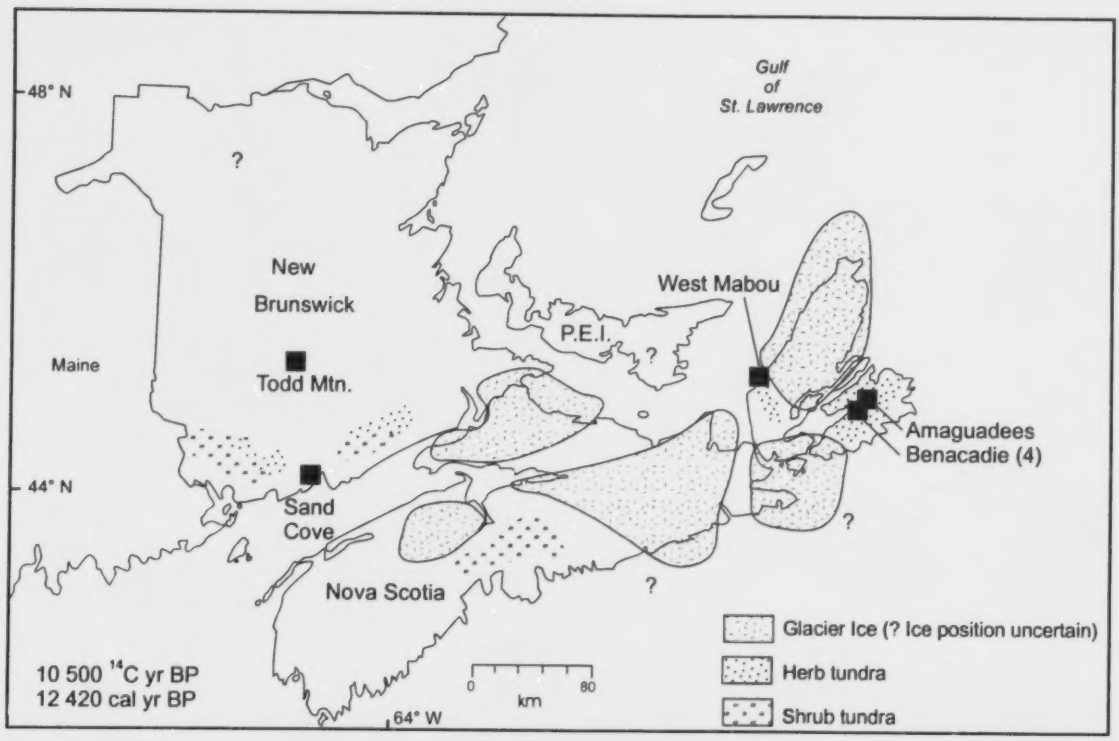


Figure 1. Location of Sand Cove Road site, Saint John, New Brunswick, showing approximate ice positions and nature of vegetation at about 10 500 yr BP (12 420 cal yr BP).

stratigraphic interpretation, radiocarbon chronology, pollen, chironomid and coleopteran records that present a picture of late-glacial environments from about 14 000 to 10 000 ^{14}C yr BP (16 790 to 11 200 cal yr BP). Readvance of small ice caps during the Younger Dryas resulted in till, diamicton, or proglacial sediments burying organic beds that had developed on the landscape. The nature of the sediments has been of key significance to the interpretation of events (Stea and Mott 1989; Mott and Stea 1993; Stea and Mott 1998). Accelerator-mass-spectrometry (AMS) dating of lake cores (Mayle *et al.* 1993a) suggest a date of 10 800 ^{14}C yr BP (12 730 cal yr BP) for the onset of Younger Dryas cooling in the Maritimes. The onset of the Younger Dryas, or GS-1 event as defined by Björck *et al.* (1998), begins a little later at 12 650 GRIP yr BP in the GRIP Greenland ice-core record. Radiocarbon ages in the text are also expressed as calibrated radiocarbon years (cal yr BP) (Stuiver and Reimer 1993) for comparison with the GRIP ice-core record.

In the Maritimes, late-glacial buried organic sites have been shown to contain insect assemblages composed largely of beetle remains (Miller 1997a). Two sites in New Brunswick, Todd Mountain, dated 11 500 ^{14}C yr BP (13 420 cal yr BP) (McNeely and McCuaig 1991; Miller 1992), and Sand Cove Road, dated 10 800 ^{14}C yr BP (12 730 cal yr BP)(McNeely and McCuaig 1991) and younger, provide the only records of late-glacial Coleoptera in the province. This paper describes a small, but significant Younger Dryas age (GS-1) assemblage from the Sand Cove Road site (Figure 1) and discusses it in a regional context.

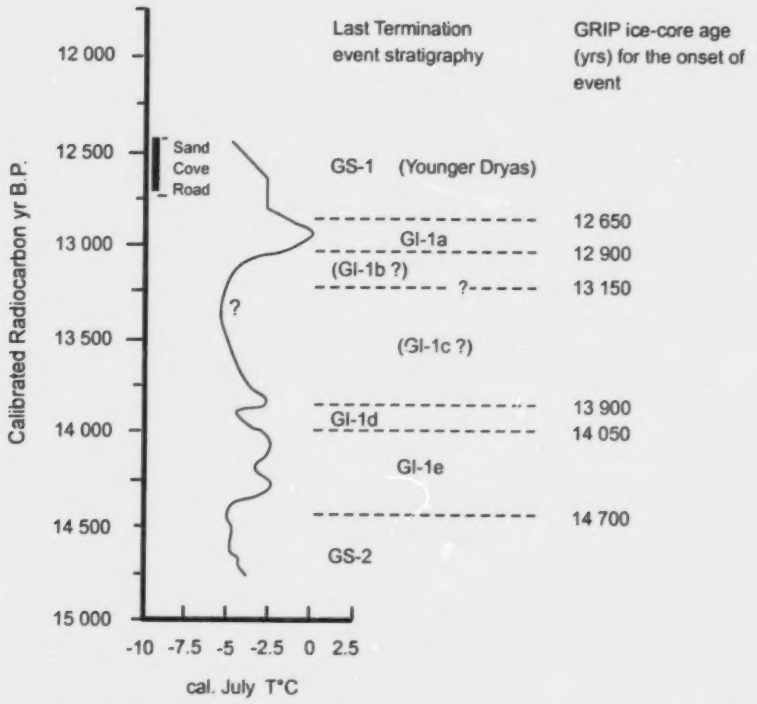


Figure 2. Mutual Climatic Range (MCR) reconstruction of the thermal history of the Maritimes Region, Canada compared with the last termination event stratigraphy proposed by Björck *et al.* (1998) based on the GRIP Greenland ice-core. Temperature expressed as departure from modern mean July temperature. Age range of the Sand Cove Road site shown at left.

Coleoptera (beetle) evidence has long been of key importance in understanding the Younger Dryas in Europe, but this has not been so in North America (Lowe *et al.* 1994). On this side of the North Atlantic Ocean, Coleoptera evidence recording Younger Dryas cooling has recently been recorded only from the Maritimes where changes in Coleoptera assemblages are consistent with a return to colder conditions. While the evidence presented by these changes in beetle assemblages is not as strong as that obtained from palynological, chironomid and stratigraphic studies, it does provide evidence for the end of the Allerød and the onset of the Younger Dryas (Miller 1997a). Palaeotemperature profiles (Figure 2) based on beetle evidence (Miller and Elias 2000) support previous work and provide a reasonable correlation with the GI-1a to GS-1 transition as recorded in the GRIP ice-core record (Björck *et al.* 1998). Toward the continental interior the Coleoptera record has not produced comparable results (Morgan 1992).

METHODS

Samples of peat and organic-rich sediment totalling 66.6 kg were taken in thicknesses of 5 and 10 cm following standard techniques for the study of Quaternary beetle fossils. All samples were submitted to standard palaeoentomological analysis using a kerosene flotation technique to isolate chitinous fragments (Elias 1994). Identified Coleoptera were mounted on micropaleontology slides or stored in alcohol and were catalogued and counted. All specimens and samples, including residues, are stored in the palaeontology collections of the New Brunswick Museum (NBMG 10727–10733).

Table 1. Late-glacial Coleoptera fauna from Sand Cove Road, Saint John, New Brunswick.

TAXA	0–10 cm	10–20 cm	20–25 cm*
CARABIDAE			
Bembidion sp. 1	1**		
Bembidion sp. 2			3
Notiophilus sp.	1		
Pterostichus cf. *P. arcticola/patruelis*?		1	
Stereocerus cf. *S. haematopus*			1
gen. indet.			2
HALIPLIDAE			
cf. Haliplus sp.			1
DYTISCIDAE			
gen. indet.	7		1
HYDROPHILIDAE			
Helophorus sp.	2		
STAPHYLINIDAE			
Acidota cf. *A. quadrata*			1
Eucnecosum cf. *E. tenue*	3		
Lathrobium sp.	1		
Olophrum boreale	7	1	4
Olophrum rotundicolle	2		
Omaliinae	18		12
Stenus spp.	1	1	1
Aleochariinae	1		
ELATERIDAE			
gen. indet.			2
CURCULIONIDAE			
gen. indet.			1

* 0–10 cm = upper stoney, organic-rich clay; 10–20 cm = fibrous peat ; 20–25 cm = organic-rich black clay.

** minimum number of individuals per level

SITE DESCRIPTION

The Sand Cove Road site, discovered by A.A. Seaman, A.G. Pronk and J.J. Thibault (New Brunswick Department of Natural Resources and Energy), is located west of Sheldon Point at the end of Sand Cove Road (Figure 1) (45°13' 30"N; 66°06' 40"W), and now lies within the Irving Nature Park. It consists of a layer of organic-rich sand and clay with matted moss, within a 2 m thick sandy gravel unit that overlies laminated marine clay. The organic unit was up to 25 cm thick where it was sampled for insect remains. The sandy gravel that contains the organic unit lies on the flank of the Sheldon Point moraine and was probably deposited within an estuarine environment (McNeely and McCuaig 1991); however, the Coleoptera suggest the organic unit developed in a freshwater-terrestrial setting. A radiocarbon date of 10 700 ±120 yr BP (GSC-4053) was obtained for the basal 2 cm of mossy organic material, while the top 2 cm of organic silt was dated at 10 800 ± 110 yr BP (GSC-4055) (12 730 cal yr BP). A bulk sample date of 10 500 ± 200 (BGS-916) (12 420 cal yr BP) was also obtained (McNeely and McCuaig 1991). Pollen analysis showed a profile with abundant herbs and shrubs (R.J. Mott in McNeely and McCuaig 1991) that suggested correlation with a late-glacial climatic deterioration equated with the Younger Dryas cooling.

Samples for Coleoptera identification were collected in 1988–89 from, as near as possible, the site sampled in 1984 by Seaman and Mott for radiocarbon dating and palynology. The 25 cm section of the buried organic deposit was sampled for Coleoptera in three units. The upper unit consisted of 10 cm of stoney, organic-rich clay. Below this was a 10 cm thick unit of fibrous peat that was underlain by a 5 cm thick unit of organic-rich black clay.

PALAEOENTOMOLOGY

A small number of Coleoptera fossils were recovered from all three of the units sampled (Table 1). The organic-rich clays from levels 0–10 and 20–25 cm were slightly more productive than the middle peat unit. A minimum of eighteen species from seven families are represented in the samples. Carabids and staphylinids comprise most of the fauna. The beetles identified either inhabit standing water or are riparian and could inhabit a modern, northern boreal environment. Two species are noted for discussion.

Olophrum boreale is a staphylinid beetle found in *Carex*, *Equisetum*, *Typha*, moss or various shrubs along the margins of lakes, bogs and slow flowing areas of streams. It is frequently collected in moist deciduous leaf litter such as that of *Alnus* and *Salix*. This is a widely distributed Holarctic species in northern areas of the boreal forest and is commonly collected from alpine areas either above or north of treeline in Alaska and Yukon. It occurs in the Nearctic region from St. Lawrence Island and the arctic tundra north of the Brooks Range, Alaska, east to the Eagle River Plains, Yukon Territory, across the Northwest Territories and Quebec to the north shore of the St. Lawrence River in eastern Quebec, south to southern Quebec and also at high elevations to Wyoming and Utah (Campbell 1983).

Stereocerus haematopus is a ground beetle that is characteristic of tundra, is abundant on dry sandy soil, but that is also found in the northern boreal forest region. In the south it is found at higher altitudes. It has a Holarctic distribution (Lindroth 1966).

PALAEOCLIMATE

The Coleoptera assemblage identified to date at Sand Cove Road is small, and very little could be said about the palaeoclimate were it not possible to place this site into the broader context of late-glacial Coleoptera in the Maritimes. Miller (1997a) divided Coleoptera assemblages from late-glacial sites in Nova Scotia and New Brunswick into three "zones", characterized by the presence of one or more species. The three zones provided a framework for examining late-glacial Coleoptera in the region: (1) a tree-line to tundra assemblage older than ca. 11 800 ^{14}C yr BP (13 760 cal yr BP); (2) a boreal assemblage from ca. 11 800 to 10 800 ^{14}C yr BP (13 760 to 12 730 cal yr BP); and (3) a northern boreo-montane assemblage from ca. 10 800 to 10 600 ^{14}C yr BP (12 730 to 12 530 cal yr BP) or younger. Zone 3 was interpreted as demonstrating a coleopteran response to climatic deterioration during the Younger Dryas chronozone.

The Sand Cove Road samples fall within zone 3, the Younger Dryas or GS-1 stadial, which began about 10 800 ^{14}C yr BP (12 730 cal yr BP) (Mayle *et al.* 1993a) in the Maritimes Region. Although Miller (1997a) suggested temperature ranges for the zones, Mutual Climatic Range (MCR) analyses (Miller and Elias 2000) demonstrate a complex temperature profile and indicate that this zonation is simplistic. MCR analysis of beetles indicated that during the Younger Dryas mean July temperatures were 3 to 5°C cooler

than present, having dropped from a regional thermal maximum at 11 100 ^{14}C yr BP (13 100 cal yr BP) that was 0.5°C warmer than present.

Between 11 800 and 10 800 ^{14}C yr BP (13 760 to 12 730 cal yr BP) glaciers in Nova Scotia retreated to local ice caps in the highland regions (Stea and Mott 1989) and New Brunswick became largely ice-free (Rampton *et al.* 1984). The beetle assemblages in Nova Scotia from this period are generally characteristic of the modern boreal forest, commonly containing bark beetles, and are consistent with the palynological interpretation of open woodland/boreal forest (Stea and Mott 1989; Mott and Stea 1993; Mott 1994; Mayle *et al.* 1993b; Mayle and Cwynar 1995). Readvance of local ice caps and the growth of areas of permanent snow cover occurred during the Younger Dryas, and was accompanied by a rise of shrub and herb pollen across the Maritimes (Mott et al. 1986; Stea and Mott 1989; Mayle *et al.* 1993a,b; Mott and Stea 1993; Stea and Mott 1998). At all sites in the Maritimes (Miller 1997a), the number of Coleoptera recovered from samples during this interval is generally less than that found in samples from older material. Sediments deposited during the Younger Dryas became more mineral-rich and less organic. Stea and Mott (1989) describe peat beds truncated by a variety of deposits including fluvial gravel and sand, lacustrine sand, silt and clay, and diamicton, possibly till.

On Cape Breton Island three sites (Figure 1)—Amaguadees, Benacadie (4) (Miller 1997b) and West Mabou (Miller 1996)—produced Coleoptera assemblages encompassing the Allerød–Younger Dryas transition. Assemblages younger than 10 800 ^{14}C yr BP (12 730 cal yr BP) from these three sites and from Sand Cove Road include the staphylinid *Olophrum boreale*. Miller (1997a) suggested that the appearance of *Olophrum boreale*, along with the presence of some other species, like *Stereocerus haematopus*, whose modern ranges extend into tundra or coastal tundra environments, marked a coleopteran response to Younger Dryas cooling. This was interpreted as the expansion in numbers of the northern boreo-montane species during the Younger Dryas. Even though the appearance of the "*O. boreale* assemblage" may not provide clear evidence of a drop in temperature, its appearance signals some change in the environment that includes both temperature change and a response to a change in vegetation cover. Pollen records from Cape Breton Island indicate a change from shrub to herb tundra at about 10 800 ^{14}C yr BP (12 730 cal yr BP) (Mott *et al.* 1986).

At both Amaguadees and Benacadie (4) (Miller 1997b), and perhaps at West Mabou (Miller 1996), appearance of the "*O. boreale* assemblage" may lag behind the onset of the Younger Dryas. Dates at Amaguadees and Benacadie (4) indicate that the greatest numbers of *O. boreale* are found sometime after 10 800 ^{14}C yr BP (12 730 cal yr BP), suggesting that beetles did not respond immediately to deteriorating climate, but gradually changed during the Younger Dryas. The Sand Cove Road beetle assemblage may also be somewhat younger than 10 800 ^{14}C yr BP (12 730 cal yr BP) and may show a similar lag in reaction to Younger Dryas cooling as found in the Cape Breton sites. A temperature profile based on MCR analyses of coleopteran assemblages for the Maritimes Region (Miller and Elias 2000) does indicate a drop in temperature at the onset of the Younger Dryas, consistent with an interpretation of a slow adaptation to cooling climate. The eurythermic species living in the Maritimes may have been able to adapt, at least for a time, to the deteriorating climate.

CONCLUSIONS

The Sand Cove Road site contains late-glacial fossil Coleoptera (beetles) from the Younger Dryas chronozone. The fossil assemblage is similar to Younger Dryas age assemblages from other sites in the Maritimes Region.

Although much of the coleopteran evidence for late-glacial climate change in the Maritimes has come from Nova Scotia, the Sand Cove Road locality demonstrates that similar events took place in New Brunswick.

The Sand Cove Road locality adds a small but significant piece to the puzzle of late-glacial climatic change in the North Atlantic. Miller and Elias (2000) argued that the climatic events recorded in the Maritimes demonstrate both similarities and dissimilarities with events recorded in the Greenland (GRIP) ice-core record (Figure 2). Differences between the records are consistent with the Ruddiman and McIntyre (1981) model of time-transgressive shifts of a North Atlantic oceanic Polar Front, hinged in such a way in the western North Atlantic that the Maritimes did not experience the rapid changes that affected the eastern side of the North Atlantic. This supports similar arguments by Lowe *et al.* (1994) for this model.

ACKNOWLEDGEMENTS

Thanks go to R.J. Mott (Geological Survey of Canada) for identifying the field site and providing information. A.V. Morgan (University of Waterloo) allowed access to the Quaternary Entomology Laboratory collections, as did Coleoptera staff of the Canadian National Collection, Agriculture Canada. Field work in New Brunswick was supported by the New Brunswick Museum. National Geographic Society Research Grant 4588-91 provided support for the Nova Scotia portions of the work. The manuscript was critically reviewed by Allen Seaman (New Brunswick Department of Natural Resources and Energy) and Donald McAlpine (New Brunswick Museum).

REFERENCES

Björck, S., Walker, M.J.C., Cwynar, L.C., Johnsen, S., Knudsen, K.-L., Lowe, J.J., Wohlfarth, B. and Intimate Members. 1998. An event stratigraphy for the last termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. Journal of Quaternary Science, **13**: 283–292.

Campbell, J.M. 1983. A revision of the North American Omaliinae (Coleoptera: Staphylinidae), the genus Olophrum Erichson. Canadian Entomologist, **115**: 577–622.

Cwynar, L.C., Levesque, A.J., Mayle, F.E. and Walker, I. 1994. Wisconsinan late-glacial environmental change in New Brunswick: a regional synthesis. Journal of Quaternary Science, **9**: 161–164.

Elias, S.A. 1994. Quaternary Insects and their Environments. Smithsonian Institution Press, Washington, DC, 284 pp.

Lindroth, C.H. 1966. The ground beetles of Canada and Alaska, 4. Opuscula Entomologica Supplementum, **29**: 409–648.

Lowe, J.J., Ammann, B., Birks, H.H., Björck, S., Coope, G.R., Cwynar, L.C., De Beaulieu, J.-L., Mott, R.J., Peteet, D.M. and Walker, M.J.C. 1994. Climatic changes in areas adjacent to the North Atlantic during the last glacial-interglacial transition (14–9 BP): a contribution to IGCP-253. Journal of Quaternary Science. **9**: 185–198.

Mayle, F.E. and Cwynar, L.C. 1995. Impact of the Younger Dryas cooling event upon lowland vegetation of Maritime Canada. Ecological Monographs. **65**: 129–154.

Mayle, F.E., Levesque, A.J. and Cwynar. L.C. 1993a. Accelerator-mass-spectrometer ages for the Younger Dryas event in Atlantic Canada. Quaternary Research, **39**: 355–360.

MAYLE, F.E., LEVESQUE, A.J. and CWYNAR. L.C. 1993b. Alnus as an indicator taxon of the Younger Dryas cooling in eastern North America. Quaternary Science Reviews, **12**: 295–305.

MCNEELY, R. and MCCUAIG, S. 1991. Geological Survey of Canada Radiocarbon Dates XXIX. Geological Survey of Canada, Paper 89-7, 134 p.

MILLER, R.F. 1992. Coleoptera fossils of late-glacial / Younger Dryas age in Eastern Canada. Geological Association of Canada, Mineralogical Association of Canada, Joint Annual Meeting, Wolfville '92, Abstracts, 17, p. A79.

MILLER, R.F. 1996. Allerød–Younger Dryas Coleoptera from western Cape Breton Island, Nova Scotia, Canada. Canadian Journal of Earth Sciences. **33**: 33–41.

MILLER, R.F. 1997a. Late-glacial Coleoptera in Maritime Canada and the transition to the Younger Dryas chronozone. Quaternary Proceedings, No. 5: 177–184.

MILLER, R.F. 1997b. Late-glacial (Allerød / Younger Dryas) Coleoptera from central Cape Breton Island, Nova Scotia, Canada. Canadian Journal of Earth Sciences, **34**: 247–259.

MILLER, R.F. and ELIAS, S.A. 2000. Late-glacial climate in the Maritimes Region, Canada, reconstructed from mutual climatic range analysis of fossil Coleoptera. Boreas, **29**: 79–88.

MORGAN, A.V. 1992. Comparisons between Europe and North America for the Younger Dryas: The insect evidence. Geological Association of Canada / Mineralogical Association of Canada, Wolfville '92, Abstracts, 17, p. A79.

MOTT, R.J. 1994. Wisconsinan late-glacial environmental change in Nova Scotia: a regional synthesis. Journal of Quaternary Science, **9**: 155–160.

MOTT, R.J., GRANT, D.R., STEA, R.R. and OCCHIETTI, S. 1986. Late-glacial climatic oscillation in Atlantic Canada equivalent to the Allerød–Younger Dryas event. Nature, **323**: 247–250.

MOTT, R.J. and STEA, R.R. 1993. Late-glacial (Allerød–Younger Dryas) buried organic deposits, Nova Scotia, Canada. Quaternary Science Reviews, **12**: 645–657.

RAMPTON, V.N., GAUTHIER, R.C., THIBAULT, J. and SEAMAN, A.A. 1984. Quaternary Geology of New Brunswick. Geological Survey Canada, Memoir 416, 77 p.

RUDDIMAN, W.F. and MCINTYRE, A. 1981. The North Atlantic Ocean during the last deglaciation. Palaeogeography, Palaeoclimatology, Palaeoecology, **35**: 145–214.

STEA, R.R. and MOTT, R.J. 1989. Deglaciation environments and evidence for glaciers of Younger Dryas age in Nova Scotia, Canada. Boreas, **18**: 169–187.

STEA, R.R. and MOTT, R.J. 1998. Deglaciation of Nova Scotia: Stratigraphy and chronology of lake sediment cores and buried organic sections. Géographie physique et Quaternaire, **52**: 3–21.

STUIVER, M. and REIMER, P.J. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. Radiocarbon, **35**: 215–230.

WALKER, I.R., MOTT, R.J. and SMOL, J.P. 1991. Allerød–Younger Dryas lake temperatures from midge fossils in Atlantic Canada. Science, **253**: 1010–1012.

WILSON, S.E., WALKER, I.R., MOTT, R.J. and SMOL, J.P. 1993. Climatic and limnological changes associated with the Younger Dryas in Atlantic Canada. Climate Dynamics, **8**: 177–187.

NEW U–Pb AGES FROM SOUTHERN NEW BRUNSWICK: PRELIMINARY RESULTS ††

B.V. Miller[1], S.M. Barr[2], L.R. Fyffe[3], and C.E. White[4]
[1]Department of Geology, University of North Carolina, Chapel Hill, North Carolina, USA 27599–3315
[2]Department of Geology, Acadia University, Wolfville, Nova Scotia, CANADA B0P 1X0
[3]New Brunswick Department of Natural Resources, Geological Surveys Branch,
P.O. Box 6000, Fredericton, New Brunswick, CANADA E3B 5H1
[4]Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia, CANADA B3J 2T9

MILLER, B.V., BARR, S.M., FYFFE, L.R., and WHITE, C.E. 2000. New U–Pb ages from southern New Brunswick: preliminary results. *In* Current Research, 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 39–50.

Southern New Brunswick consists of narrow, fault-bounded terranes containing rocks of contrasting character and age. The number and tectonostratigraphic significance of these terranes is controversial. Detailed field mapping and accurate and precise radiometric ages are essential in determining the geological history in this complex area in which few units contain fossils. A project is underway in southern New Brunswick to date key stratigraphic and intrusive units by the U–Pb method. Three preliminary ages are reported here: 555.5 ± 3.1 Ma for a rhyolite from the Coldbrook Group in the St. Martins area (Caledonia terrane), 436 ± 10 Ma for granite in the Kingston terrane near Beaver Harbour, and ca. 440 for a crystal tuff in the Bayswater Group near Pocologan (Kingston terrane).

Le Sud du Nouveau-Brunswick est constitué de terranes étroits limités par des failles renfermant des roches de caractères et d'âges opposés. Le nombre et l'importance tectonostratigraphique de ces terranes prêtent à la controverse. Il est essentiel de réaliser des travaux détaillés de cartographie sur le terrain et d'établir de façon exacte et précise leurs âges radiométriques pour déterminer quel a été le passé géologique de ce secteur complexe à l'intérieur duquel quelques unités renferment des fossiles. Des chercheurs sont présentement en train de mener un projet dans le Sud du Nouveau-Brunswick pour définir l'âge d'unités stratigraphiques et intrusives clés au moyen de la méthode de datation au U–Pb. Les présentes font état de trois datations préliminaires: 555.5 ± 3.1 Ma dans le cas de rhyolite du groupe de Coldbrook, dans la région de St. Martins (terrane Caledonia); 436 ± 10 Ma dans le cas de granite du terrane de Kingston, près de Beaver Harbour; et approximativement 440 Ma dans le cas de tuf cristallin du groupe de Bayswater, près de Pocologan (terrane de Kingston).

INTRODUCTION

Accurate and precise ages of rock units in southern New Brunswick have been shown to be essential for advancing the understanding of this geologically complex area (Figure 1). For example, as a result of such ages, it has been recognized that the Caledonian Highlands include two major volcanic–sedimentary–plutonic suites that differ in age by approximately 50 Ma (Barr *et al.* 1994; Barr and White 1999). Similarly,

†† Funding provided by the New Brunswick Geological Surveys Branch ordinary budget and a research grant to S.M. Barr from the Natural Sciences and Engineering Research Council of Canada.

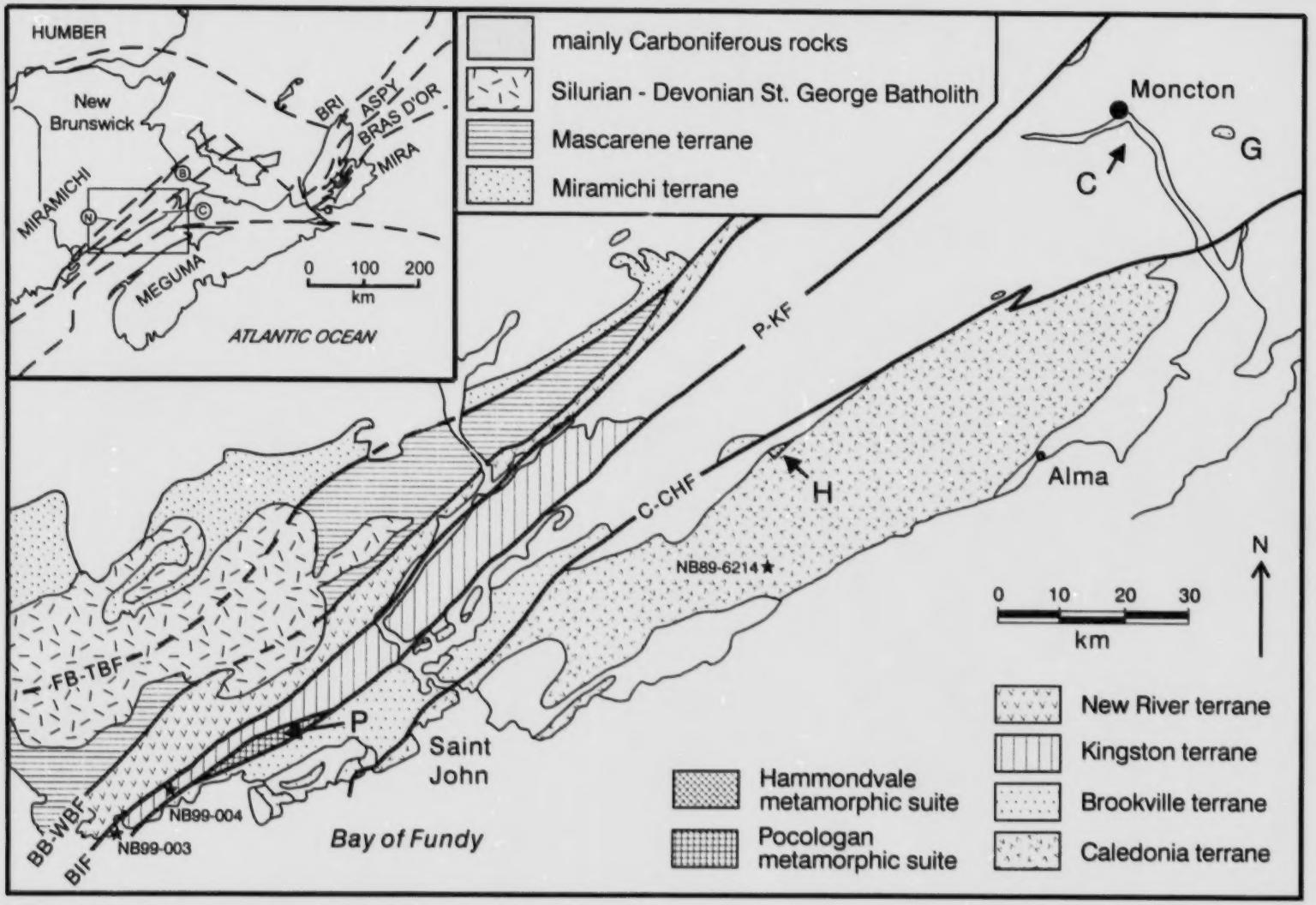


Figure 1. Geological terranes in southern New Brunswick (after Barr *et al.* 1999), showing approximate locations of the samples collected for U–Pb dating (numbered stars). Inset map shows the location of the study area in southern New Brunswick, as well as terranes in the northern Appalachian orogen (after Barr *et al.* 1998). Abbreviations: **BB-WBF**—Back Bay–Wheaton Brook fault; **BIF**—Belleisle fault; **BRI**—Blair River inlier;**C**—Coverdale; **C-CHF**—Caledonia–Clover Hill fault; **FB-TBF**—Fall Brook–Taylor Brook fault; **G**—Gaytons granite; **H**—Hammondvale metamorphic suite; **P-KF**—Pocologan–Kennebecasis fault; **P**—Pocologan metamorphic suite.

it has been shown that the Brookville Gneiss in the Saint John area is not the basement on which the carbonate-clastic units of the Green Head Group were deposited but instead is at least 200 Ma younger (Bevier *et al.* 1990; Dallmeyer *et al.* 1990). U–Pb dating was critical to the recognition that the Kingston belt is not a Late Precambrian bimodal dyke complex but, instead, a Silurian volcanic arc complex (Doig *et al.* 1990; Barr *et al.* 1997, 1999; M.J. McLeod, personal communication, 1996). A series of Late Neoproterozoic U–Pb ages from volcanic and plutonic units in the New River terrane has confirmed that it is dominantly Precambrian, although its relationship to the Brookville and Caledonia terranes remains uncertain (Johnson and McLeod 1996; Currie and McNicoll 1999; Johnson 1999).

In order to tackle specific remaining problems in the region, a new programme of U–Pb dating was initiated in 1999. The purpose of this paper is to report preliminary results from this study. The U–Pb data, sample location maps, and more detailed interpretations of the significance of the data will be published as the project progresses.

GEOLOGICAL SETTING

Southern New Brunswick is characterized by long narrow belts of rocks of contrasting composition and age, separated by major faults. Barr and White (1989, 1996a) divided the Avalonian terrane of Fyffe and Fricker (1987) into four separate belts or terranes, the tectonostratigraphic significance of which remains controversial. The characteristics of each of these terranes and the adjacent Mascarene terrane of Fyffe and Fricker (1987) (Figure 1) are summarized below to provide background for the geochronological study.

(1) The **Caledonia terrane** includes mainly Neoproterozoic and Cambrian rocks located south of the Caledonia–Clover Hill fault (Figure 1). Although this fault is a Carboniferous feature (e.g., St. Peter 1993), it separates contrasting Precambrian rocks and may have had an older movement history, possibly marking a terrane boundary (Barr and White 1989; White and Barr 1996). Based on differences in lithology and age (Bevier and Barr 1990; Barr *et al.* 1994), Neoproterozoic volcanic and sedimentary rocks of the Caledonia terrane are divided into two groups. The ca. 620 Ma Broad River Group is exposed mainly in the northeastern and southern parts of the terrane, whereas the ca. 560–550 Ma Coldbrook Group forms most of the western and northern part (Figure 1). Two large suites of plutonic rocks occur with the volcanic rocks. The composite, ca. 620 Ma, Point Wolfe River and related plutons are cogenetic with the Broad River Group, and the bimodal, ca. 560–550 Ma, Bonnell Brook and related plutons are cogenetic with basalt and rhyolite of the upper part of the Coldbrook Group (Barr and White 1996a, 1999). On the basis of petrological characteristics, the ca. 620 Ma rocks were interpreted to have formed in a continental margin magmatic arc, whereas the ca. 560–550 Ma rocks formed in a subsequent extensional regime (Barr and White 1996b, 1999). The Coldbrook Group is overlain by a Lower Paleozoic platformal sedimentary sequence containing an Acado-Baltic fauna and traditionally termed the Saint John Group (e.g., Tanoli and Pickerill 1988). Small areas of ca. 479 Ma dacitic and rhyodacitic volcanic rocks (Grassy Lake Formation) and Devonian volcanic and sedimentary rocks may also be present, although the ages are not yet well constrained by U–Pb data (Barr *et al.* 1994).

Metamorphic rocks of the Hammondvale metamorphic suite form a fault-bounded area on the northwestern margin of the Caledonia terrane, adjacent to the Caledonia–Clover Hill fault (Figure 1). They consist dominantly of albite–muscovite schist, with minor interlayered calc-silicate rocks, marble, and amphibolite,

and contain mineral assemblages indicating high-pressure metamorphism (White 1996; White *et al.* 2000). Muscovite from the schist yielded $^{40}Ar/^{39}Ar$ cooling ages of 603–617 Ma (White *et al.* 2000). The Hammondvale metamorphic suite is interpreted to represent an accretionary complex formed at ca.620 Ma in a southeast-dipping subduction zone at which the Broad River Group and related plutons were generated. Its presence indicates that the Caledonia–Clover Hill fault marks a major continental suture zone.

(2) The **Brookville terrane** is located between the Caledonia–Clover Hill fault to the southeast and the Pocologan–Kennebecasis fault on the northwest (Figure 1). Like the Caledonia–Clover Hill fault, the Pocologan–Kennebecasis fault is a brittle Carboniferous fault, but is interpreted to mark the location of an older suture. Mapping and petrological studies of rocks in this area have led to the recognition of a new metamorphic suite (Pocologan metamorphic suite) that, like the Hammondvale suite, preserves vestiges of high-pressure metamorphism (Grace and Barr 2000).

The Brookville terrane consists of the Green Head Group, Brookville Gneiss, Dipper Harbour volcanic unit, and abundant plutons (White and Barr 1996). The Green Head Group includes the Ashburn Formation (dominantly marble with minor metaclastic rocks) and the Martinon Formation (dominantly metasiltstone with minor calc-silicate rocks, quartzite, conglomerate, and marble); the two units are interpreted to be lateral facies equivalents (White and Barr 1996). Based on locally preserved stromatolites, Hofmann (1974) proposed that the Green Head Group is Neohelikian (Mesoproterozoic) in age, but more recent assessment suggests that it could be as young as ca. 750 Ma (H. Hofmann, written communication, 1991). An early Neoproterozoic or late Mesoproterozoic age for the Green Head Group is supported by five U–Pb ages ranging from 1230 Ma to 2723 Ma, obtained for detrital zircon grains from a quartzitic conglomerate sample (D. Davis, personal communication, 1995). The Green Head Group is in tectonic contact along the MacKay Highway shear zone (White 1996) with the Brookville Gneiss, a locally migmatitic paragneiss with sheets of granodioritic to tonalitic orthogneiss, minor calc-silicate and marble layers, and rare quartzite and amphibolite. The paragneiss, which comprises about 75% of the Brookville Gneiss, contains detrital zircon indicating a maximum depositional age of ca. 640 Ma (Bevier *et al.* 1990). The orthogneiss has an igneous crystallization age of 605 ± 3 Ma, and was metamorphosed to amphibolite facies at 564 ± 6 Ma (Bevier *et al.* 1990; Dallmeyer *et al.* 1990). These dates indicate that, contrary to earlier interpretations (e.g., Nance 1987), the Brookville Gneiss is younger than the Green Head Group and, hence, does not represent its basement. However, the original relationship between the two units remains problematic.

The Green Head Group has been intruded by plutons that range in composition from dioritic to granitic, and which have yielded U–Pb dates of ca. 555 Ma to 537 Ma (White 1996; Currie and Hunt 1991; Currie and McNicoll 1999). Their petrological characteristics suggest that they constitute a typical calc-alkalic I-type granitoid suite, probably emplaced in a continental margin subduction zone (White 1996; Eby and Currie 1996). The ca. 550 Ma Dipper Harbour volcanic unit (Zain Eldeen 1991) may represent part of the contemporaneous volcanic arc complex. Scattered small gabbroic to ultramafic plutons intruded the older units and are possibly Silurian in age, by comparison with similar mafic plutons elsewhere in southwestern New Brunswick and Maine (West *et al.* 1992). The Gaytons granite, exposed in a quarry in the Moncton area (Figure 1), is inferred to be located in the Brookville terrane, but has yielded a Devonian age of ca. 392 Ma (M. Hamilton, personal communication, 1997). Granite of similar age and petrological character occurs in close association with anorthosite and gabbro in drill core from Coverdale, southwest of Moncton (Boyle and Stirling 1994; M. Hamilton, personal communication, 1997) (Figure 1). The age of the Coverdale anorthosite and gabbro is unknown, but may be as young as Devonian, based on the close association with Devonian granite.

(3) The **Kingston terrane** is separated from the Brookville terrane to the southeast by the Pocologan–Kennebecasis fault, and is bounded on the north by the Belleisle fault (Figure 1). Both boundaries are obscured by the presence of mylonitic rocks, for which the protolith is not clear. Mapping by Barr *et al.* (1999) suggests that the mylonitic rocks along the Belleisle fault are part of the New River terrane to the north, and those along the Pocologan–Kennebecasis fault are part of the Brookville terrane and Pocologan metamorphic suite. Rocks of the Kingston terrane are not evidently mylonitic (Barr *et al.* 1999).

Traditionally, the Kingston belt was assumed to consist mainly of the Kingston Dyke Complex, a bimodal dyke swarm of Late Precambrian age. However, recent U–Pb dating (Doig *et al.* 1990; M. McLeod, personal communication, 1997) and mapping have shown that most of the belt consists of Silurian (ca. 435–440 Ma) metavolcanic rocks of the Bayswater Group, intruded by high-level comagmatic granitoid plutons (Barr and White 1998; Barr *et al.* 1997, 1999). The Bayswater Group consists mainly of dacitic and rhyolitic crystal and lithic-crystal lapilli tuff, with less abundant basaltic to andesitic flows and tuffs, rare dacitic and rhyolitic flows, and minor volcanogenic siltstone. The associated plutons are characterized by fine grain size and granophyric and locally porphyritic textures, consistent with high-level emplacement. Both the Bayswater Group and granitoid plutons are intruded by abundant mafic dykes, now amphibolite, which have been regionally metamorphosed together with their host rocks to upper greenschist facies. The time of metamorphism was Devonian, based on $^{40}Ar/^{39}Ar$ dating (Nance and Dallmeyer 1993). The volcanic and plutonic rocks appear to be calc-alkalic, emplaced late in the evolution of a continental margin volcanic arc (Barr *et al.* 1997, 1999). In contrast, the mafic dykes are tholeiitic, and may have formed in a subsequent extensional tectonic regime. The nature of the crust underlying the Kingston terrane and its relationship to adjacent Proterozoic terranes is unknown because of the faulted margins.

(4) The **New River terrane** (Johnson and McLeod 1996) is separated from the Kingston terrane to the southeast by the Belleisle fault and from mainly Silurian and younger rocks of the Mascarene terrane to the northwest by the Wheaton Brook fault. The New River terrane consists mainly of Late Proterozoic (ca. 620 Ma and ca. 555 Ma) plutonic and volcanic rocks (Johnson and McLeod 1996; Currie and McNicoll 1999). The volcanic rocks include spherulitic and aphyric felsic flows, felsic tuffs, and minor mafic volcanic rocks. The plutonic rocks are a compositionally expanded suite ranging from gabbro to granite. The tectonic setting has not been investigated in detail, but an arc setting appears likely on the basis of lithological characteristics (Johnson and McLeod 1996). Locally the ca. 550 Ma rocks are unconformably overlain by Early and Middle Cambrian mafic and minor felsic volcanic rocks with interlayered sedimentary rocks containing an Acado-Baltic fauna (Tanoli and Pickerill 1988). Other Cambrian units in the terrane include the ca. 515 Ma, dominantly felsic, arc-related, Mosquito Lake volcanic unit, and sedimentary rocks of the Late Cambrian Matthew Lake beds. Areas of Late Ordovician and Silurian arc-related (?) volcanic and sedimentary rocks are also present (Johnson and McLeod 1996).

Traditionally, the Avalon zone boundary has been placed at the Belleisle fault (Williams 1978; Fyffe and Fricker 1987). However, because of the age and composition of the New River terrane, more recent workers have placed the boundary at the northern margin of the Mascarene terrane (e.g., Whalen *et al.* 1996). The recognition of some 515 Ma volcanic rocks in the New River terrane supports the correlation by Fyffe and Fricker (1987) of at least part of the belt with the Cambrian Ellsworth terrane of Maine (Stewart *et al.* 1995).

(5) The **Mascarene terrane** consists mainly of Silurian to Early Devonian siliciclastic sedimentary and volcanic rocks of the Mascarene Group. It is flanked to the northwest by the Ordovician St. Croix terrane, and to the southeast by the New River terrane described above. The northwestern margin is now mainly

faulted but apparently represents a regional unconformity (Fyffe *et al.* 1999). The southern margin is obscured by the St. George batholith and related plutons, and numerous faults (Fyffe *et al.* 1999). Overall relationships among the Kingston, New River, and Kingston terranes are a major unresolved problem (see discussion in Fyffe *et al.* 1999).

METHODS

Zircon U–Pb dating is being conducted at the Isotope Geochemistry Laboratory at the University of North Carolina–Chapel Hill. In the present study, zircon grains were separated from samples of 8 to 25 kg using standard techniques including crushing, Rogers table, heavy liquids and a Frantz isodynamic separator. Zircon grains were hand picked under a binocular microscope in order to select grains of similar morphological types that are as clear, crack-free, and inclusion-free as possible. All zircon fractions were highly abraded to remove the outermost portions of grains that are most likely to have been affected by Pb-loss. Detailed analytical procedures are described in Miller *et al.* (in review).

PRELIMINARY RESULTS

Rhyolite of the Coldbrook Group, Caledonia terrane

An age range of 560–550 Ma for the redefined Coldbrook Group (Barr and White 1999) was based on U–Pb ages of 548 ± 1 Ma from an ignimbritic rhyolite flow in the central part of the Caledonian Highlands, 559 ± 5 Ma from a felsic tuff in the northern part of the highlands, and 554 +14/–1 from a dacite unit in the Saint John area (Bevier and Barr 1990; Barr *et al.* 1994). The age is further supported by its inferred comagmatic relationship with the 550 ± 1 Ma Bonnell Brook syenogranite (Bevier and Barr 1990), the 551 ± 5 Ma Upham Mountain syenogranite (Barr *et al.* 1994), and the 557 ± 3 Ma Mechanic Settlement Pluton (Grammatikopoulos *et al.* 1995). However, rhyolite and basalt also are components of the ca. 620 Ma Broad River Group and, hence, the extrapolation of Coldbrook Group units throughout the 100 km extent of the Caledonian Highlands remains somewhat uncertain. Also, younger Ordovician and Devonian rhyolites have been reported from the St. Martins area, and the extent of rocks of those ages is not well known (Barr *et al.* 1994; Barr and White 1999).

Previous attempts to further constrain the age of the Coldbrook Group by dating rhyolite or dacite units had not been successful because of lack of zircon in the samples (as summarized in Table 1 in Barr and White 1999). Hence, an additional rhyolite sample was dated as part of the present project. The sample (NB89-6214) was collected from rhyolite unit Z_{Cr} of Barr and White (1999), where the unit crosses Highway 111 north of St. Martins. The rock is a cryptocrystalline rhyolite with spherulitic and eutaxitic texture. It contains scattered microphenocrysts of quartz and feldspar.

Zircon grains separated from sample NB89-6214 were mostly small (50 to 120 μm in longest dimension) prismatic grains with low aspect ratios (less than 3:1) and contained numerous dark inclusions. Broken fragments of very large grains were relatively inclusion-free, although none of these large grains survived sample processing intact. In order to avoid potentially inherited core material and other inclusions, three of the five analyzed fractions were groups of six to twenty-eight pyramidal tips that broke off prismatic grains during sample processing. Another zircon fraction consisted of twenty-six small prismatic grains (approx. 60 μm long), selected to contain as few inclusions as possible. The fifth zircon fraction consisted of clear, inclusion-free, fragments broken from very large grains. All five form a discordant array (MSWD = 0.12) with an upper-intercept age of 555.5 ± 3.1 Ma and a lower intercept within error of the origin,

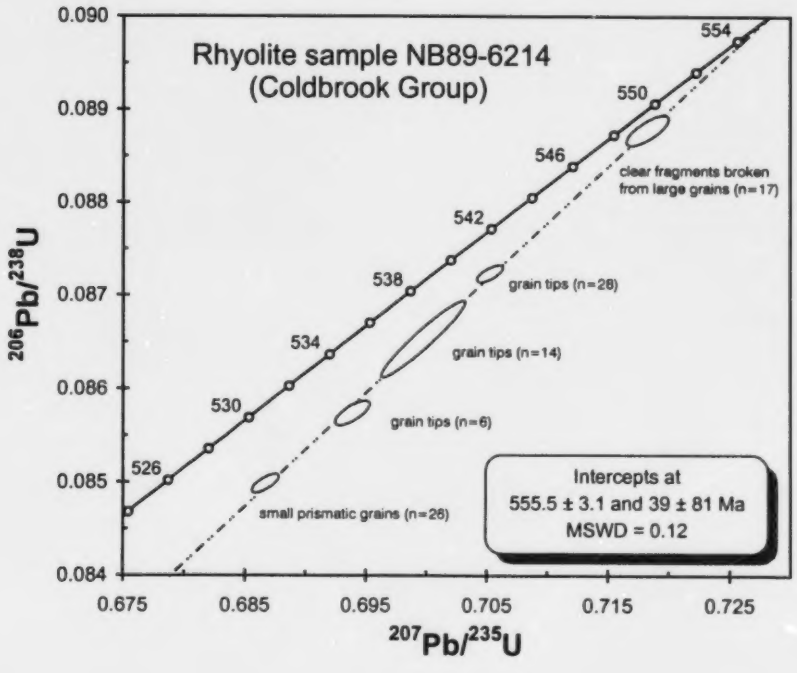


Figure 2. U–Pb concordia diagram for sample NB89-6214.

suggesting recent Pb-loss (Figure 2). We consider the upper-intercept age as the time of zircon crystallization in the magma, and within error of the time of rhyolite extrusion.

The age is similar to other ages obtained from the Coldbrook Group, and further corroborates the interpretation that that unit has a restricted range in age (ca. 560–550 Ma; Barr and White 1999) throughout the Caledonian Highlands.

Granite and tuff in the Kingston terrane

Doig *et al.* (1990) reported U–Pb ages of ca. 430 Ma for fine-grained granite samples from two locations on Highway 7 near Saint John. Although interpreted by Doig *et al.* (1990) to be felsic dykes, Barr and White (1998) showed that these rocks are part of the Sand Point pluton. Additional ages of ca. 438 Ma and 435 Ma were obtained from the Centreton granite and a tuff in the Bayswater Group, both in the Kingston Peninsula (M. McLeod, personal communication, 1997).

In order to document the extent of Silurian rocks in the Kingston terrane, two additional units were dated in the southwestern part of the belt (Figure 1).

(a) West Branch Reservoir granite: Approximately half of the southwestern part of the Kingston terrane consists of pink granitoid rocks termed the West Branch Reservoir pluton (Barr *et al.* 1999). The dated granite sample (NB99-003) was collected from near the lighthouse at the southern entrance to Beaver Harbour (Figure 1). The sample consists of plagioclase laths in a somewhat recrystallized, perhaps originally granophyric, groundmass of quartz and K-feldspar. Also present are scattered flakes of biotite and rare granular epidote.

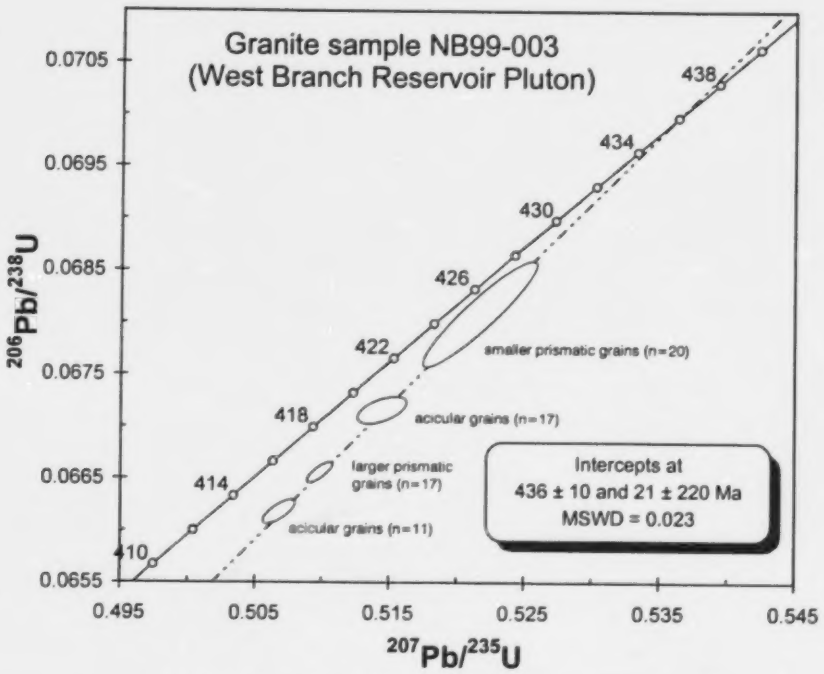


Figure 3. U–Pb concordia diagram for sample NB99-003.

Zircon grains separated from sample NB99-003 are of many different morphologies from acicular grains with aspect ratios up to about 5:1, to nearly equant multi-facted grains. Four analyzed fractions included two fractions of clear acicular grains, and two fractions of tan-coloured larger prismatic grains with slightly rounded (resorbed?) corners and tips, which were separated into larger grains (100–140 μm long) and smaller grains (60–80 μm long) fractions. All four fractions lie on a discordia line (MSWD = 0.02) with an upper intercept at 436 ± 10 Ma and a lower intercept within error of the origin, suggesting recent Pb-loss (Figure 3). We interpret the upper intercept age as the time of crystallization of the granite. The age is the same (within error) as previously reported U–Pb ages from the Centreton and Sand Point plutons, and confirms that granitic plutons throughout the terrane are Silurian in age.

(b) Tuff from the Bayswater Group: A tuffaceous unit was sampled from a large roadcut on Highway 1 near the Seelys Cove exit. The roadcut consists of varied crystal tuff and lithic tuff, intruded by sparse mafic dykes. Although these rocks are not mylonitic, they are located near the northern margin of the Pocologan shear zone (Park et al. 1994). The dated sample (NB99-004) is a dacitic to rhyolitic crystal tuff, and consists of about 40% crystals, mainly plagioclase and K-feldspar, in a fine-grained felsic matrix with abundant sericite and scattered epidote.

Zircon grains from sample NB99-004 were of a variety of shapes and sizes. Three analyzed fractions consisted of a clear smaller (80–100 μm) and larger (100–160 μm) prismatic grains, both with slightly resorbed corners and tips, and one fraction of slightly metamict light brown partial grains broken from very large zircon grains. The three fractions form a discordant array with scatter significantly in excess of that expected from laboratory uncertainties alone (MSWD = 5.8) (Figure 4). More analyses are underway to better define the discordant array. However, initial indications suggest strongly that the upper intercept age of ca. 441 Ma is the age of zircon crystallization in the magma, and likely approximates the age of

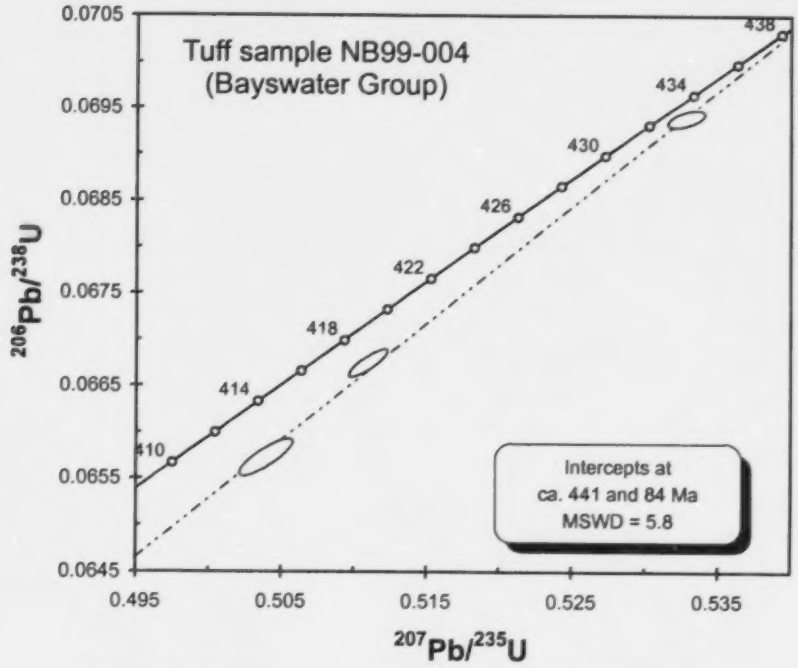


Figure 4. U–Pb concordia diagram for sample NB99-004.

eruption of the tuff. If confirmed by additional analyses, the age corroborates the unpublished age (M. McLeod, personal communication, 1997) from volcanic rocks 35 km to the northeast in the Kingston Peninsula. Combined with the granite age above, this date further supports the interpretation that the Kingston terrane is composed of cogenetic Silurian volcanic and plutonic rocks (Barr *et al.* 1999).

ADDITIONAL SAMPLES

Because of lack of other age controls (e.g., fossils), precise radiometric dating is of major importance in understanding complex geological relationships in southern New Brunswick. This project will continue, in combination with on-going mapping, to obtain ages from the Blacks Harbour pluton in the New River terrane, from a rhyolite unit in the Mascarene terrane, granitic units in the Pocologan metamorphic suite (Grace and Barr 2000), granodiorite at McCarthy Point in the Brookville terrane, and dacite in the Coldbrook Group of the Caledonia terrane.

ACKNOWLEDGEMENTS

We thank Sue Johnston and Malcolm McLeod for their on-going collaboration in southern New Brunswick. We thank David McMullin for reviewing the manuscript.

REFERENCES

Barr, S.M., and White, C.E. 1989. Re-interpretation of Precambrian stratigraphy in southern New Brunswick. *In* Project Summaries for 1989 and Fourteenth Annual Review of Activities. *Edited by* S.A. Abbott. New Brunswick

Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 89-2, pp. 182–189.

BARR, S.M. and WHITE, C.E. 1996a. Contrasts in late Precambrian–early Paleozoic tectonothermal history between Avalon Composite Terrane *sensu stricto* and other peri-Gondwanan terranes in southern New Brunswick and Cape Breton Island, Canada. *In* Avalonian and related peri-Gondwanan terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pp. 95–108.

BARR, S.M. and WHITE, C.E. 1996b. Tectonic setting of Avalonian volcanic and plutonic rocks in the Caledonian Highlands, southern New Brunswick, Canada. Canadian Journal of Earth Sciences, **33**:156–168.

BARR, S.M., and WHITE, C.E. 1998. Geology of the Kingston Peninsula (parts of NTS 21G/08, G/09, H/05, and H/12), Kings and Queens counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-16. (scale 1:50 000)

BARR, S.M., and WHITE, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

BARR, S.M., BEVIER, M.L., WHITE, C.E., and DOIG, R. 1994. Magmatic history of the Avalon terrane of southern New Brunswick, Canada, based on U–Pb (zircon) geochronology. Journal of Geology, **102**: 399–409.

BARR, S.M., WHITE, C.E., and MCLEOD, M.J. 1997. Geology of the Kingston Peninsula, southern New Brunswick: a preliminary report. *In* Current Research 1996. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resources Report 97-4, pp. 1–20.

BARR, S.M., RAESIDE, R.P., and WHITE, C.E. 1998. Geological correlations between Cape Breton Island and Newfoundland, northern Appalachian orogen. Canadian Journal of Earth Sciences, **35**:1252–1270.

BARR, S.M., WHITE, C.E., and MCLEOD, M.J. 1999. Geology of the Kingston terrane, southern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resources Report 99-4, pp. 1–17.

BEVIER, M.L. and BARR, S.M. 1990. U–Pb age constraints on the stratigraphy and tectonic history of the Avalon terrane, New Brunswick, Canada. Journal of Geology, **98**: 53–63.

BEVIER, M.L., WHITE, C.E., and BARR, S.M. 1990. Late Precambrian U–Pb ages for the Brookville Gneiss, southern New Brunswick. Journal of Geology, **98**: 955–965.

BOYLE, D.R., and STIRLING, J.A.R. 1994. Geochemistry, mineralogy, and possible origin of the Coverdale Ti–P–ferrogabbro complex, New Brunswick. *In* Nineteenth Annual Review of Activities. *Edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 14, p. 4.

CURRIE, K.L. and HUNT, P.A. 1991. Late Precambrian activity near Saint John, New Brunswick. *In* Radiogenic Age and Isotopic Studies. Report 4; Geological Survey of Canada, Paper 90-2, p. 11–17.

CURRIE, K.L., and MCNICOLL, V.J. 1999. New data on the age and geographic distribution of Neoproterozoic plutons near Saint John, New Brunswick. Atlantic Geology, **35**: 157–166.

DALLMEYER, R.D., DOIG, R., NANCE, R.D., and MURPHY, J.B. 1990. $^{40}Ar/^{39}Ar$ and U–Pb mineral ages from the Brookville Gneiss and Green Head Group: implications for terrane analysis and evolution of Avalonian "basement" in southern New Brunswick; Atlantic Geology, **26**: 247–257.

DOIG, R., NANCE, R.D., MURPHY, J.B., and CASSEDAY, R.P. 1990. Evidence for Silurian sinistral accretion of Avalon composite terrane in Canada; Journal of the Geological Society, London, **147**: 927–930.

EBY, G.N., and CURRIE, K.L. 1996. Geochemistry of the granitoid plutons of the Brookville terrane, Saint John, New Brunswick, and implications for development of the Avalon Zone. Atlantic Geology, **32**: 247–268.

FYFFE, L.R., and FRICKER, A.A. 1987. Tectonostratigraphic terrane analysis of New Brunswick. Maritime Sediments and Atlantic Geology, **23**: 113–122.

FYFFE, L.R., PICKERILL, R.K., and STRONGER, P. 1999. Stratigraphy, sedimentology, and structure of the Oak Bay and Waweig formations, Mascarene Basin: Implications for the paleotectonic evolution of southwestern New Brunswick. Atlantic Geology, **35**: 59–84.

GRACE, E.M., and BARR, S.M. 2000. Determination of protoliths and pressure–temperature conditions of metamorphic rocks in the "Pocologan mylonite zone", southern New Brunswick. *In* Atlantic Geoscience Society Colloquium, Program and Abstracts, Fredericton, New Brunswick, Feb. 10–12, 2000, p. 28.

GRAMMATIKOPOULOS, A.L., BARR, S.M., REYNOLDS, P., and DOIG, R. 1995. Petrology and age of the Mechanic Settlement Pluton, Avalon terrane, southern New Brunswick. Canadian Journal of Earth Sciences, **32**: 2147–2158.

HOFMANN, H.J. 1974. The stromatolite *Archaeozoon acadiense* from the Proterozoic Green Head Group of Saint John, New Brunswick. Canadian Journal of Earth Sciences, **11**: 1098–1115.

JOHNSON, S.C. 1999. Bedrock geology of the Long Reach area, Kings County, southern New Brunswick. *In* Abstracts 1999: 24th annual Review of Activities. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 99-3, p. 21.

JOHNSON, S.C. and MCLEOD, M.J. 1996. Tectonic significance of the New River belt: a unique segment along the western margin of the Avalon composite terrane, southern New Brunswick *In* Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pp. 149–164.

MILLER, B.V., STEWART, K.G., MILLER, C.F., and THOMAS, C.W. In review. U–Pb ages from the Lick Ridge eclogite, western North Carolina: Taconian eclogite metamorphism followed by Acadian and Alleghanian cooling. Submitted to Geology.

NANCE, R.D. 1987. Model for the Precambrian evolution of the Avalon terrane in southern New Brunswick, Canada. Geology, **15:** 753–756.

NANCE, R.D., and DALLMEYER, R.D. 1993. $^{40}Ar/^{39}Ar$ amphibole ages from the Kingston complex, New Brunswick: Evidence for Silurian-Devonian tectonothermal activity and implications for the accretion of the Avalon composite terrane. Journal of Geology, **101**: 375–388.

PARK, A.F., WILLIAMS, P.F., RALSER, S., and LEGER, A. 1994. Geometry and kinematics of a major crustal shear zone segment in the Appalachians of southern New Brunswick. Canadian Journal of Earth Sciences, **31**: 1523–1535.

ST. PETER, C. 1993. Maritimes Basin evolution: key geologic and seismic evidence from the Moncton Subbasin of New Brunswick. Atlantic Geology, **29**: 233–270.

STEWART, D.B., UNGER, J.D., and HUTCHINSON, D.R. 1995. Silurian tectonic history of Penobscot Bay region, Maine. Atlantic Geology, **31**: 67–79.

TANOLI, S.K., and PICKERILL, R.K. 1988. Lithostratigraphy of the Cambrian–Lower Ordovician Saint John Group, southern New Brunswick. Canadian Journal of Earth Sciences, **25**: 669–690.

WEST, D.P., Jr., LUDMAN, A., and LUX, D.R. 1992. Silurian age for the Pocomoonshine gabbro–diorite, southeastern Maine, and its regional tectonic implications. American Journal of Science, **292**: 253–273.

WHALEN, J.B., FYFFE, L.R., LONGSTAFFE, F.J., and JENNER, G. 1996. The position and nature of the Gander–Avalon boundary, southern New Brunswick, based on geochemical and isotopic data from granitoid rocks. Canadian Journal of Earth Sciences, **33**: 129–139.

WHITE, C.E. 1996. Geology, geochronology, and tectonic evolution of the Brookville terrane, southern New Brunswick. Ph.D. thesis, Dalhousie University, Halifax, Nova Scotia, Canada.

WHITE, C.E. and BARR, S.M. 1996. Geology of the Brookville terrane, southern New Brunswick, Canada. *In* Avalonian and related peri-Gondwanan terranes of the Circum-North Atlantic. *Edited by* R.D. Nance and M.D. Thompson. Geological Society of America, Special Paper 304, pp. 95–108.

WHITE, C.E., BARR, S.M., JAMIESON, R.A. and REYNOLDS, P.H. 2000. The Hammondvale metamorphic suite: part of an exhumed Neoproterozoic convergent margin in the Avalon Terrane, southern New Brunswick. *In* Atlantic Geoscience Society Colloquium, Program and Abstracts, Fredericton, New Brunswick, Feb. 10–12, 2000: 45.

WILLIAMS, H. 1978. Tectonic lithofacies map of the Appalachians: Memorial University Map No. 1, Department of Geology, Memorial University of Newfoundland, Canada.

ZAIN ELDEEN, U. 1991. The geology of the Dipper Harbour area, southern New Brunswick, Canada. M.Sc. thesis, Ohio University, Athens, Ohio.

TILL GEOCHEMISTRY AND GLACIAL DISPERSAL IN THE EASTERN PART OF THE WOODSTOCK (NTS 21 J/04) MAP AREA, CARLETON COUNTY, NEW BRUNSWICK †

Allen A. Seaman
New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,
P.O. Box 6000, Fredericton, New Brunswick, CANADA E3B 5H1 (e-mail: allen.seaman@gnb.ca)

SEAMAN, A.A. 2000. Till geochemistry and glacial dispersal in the eastern part of the Woodstock (NTS 21 J/04) map area, Carleton County, New Brunswick. *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 51–71.

The Woodstock (NTS 21 J/04) map area is traversed by the Woodstock Fault, which is known to be associated with Au–As–Sb mineralization in the Fosterville (NTS 21 G/13) map area to the south. Also, numerous mineral occurrences, primarily chalcopyrite and associated minerals, are known from the part of the Woodstock map area to the east of the fault. Consequently, till sampling was carried out in the area during 1999 using the standard 2 km sampling grid adjacent to and east of the fault, and a variant of this grid involving sampling every second grid point for the area to the west. The results suggest that mineralization may be associated with the Woodstock Fault along its length to the south of the Town of Woodstock. Mineralization may also occur in the area to the west of the Woodstock Fault, perhaps associated with minor parallel or cross-cutting faults. In the area to the east of the Woodstock Fault, most of the known mineral occurrences appear to be too small in surface extent to generate till anomalies at the scale of sampling. However, a major Cu anomaly is associated with the known occurrences near Connell Mountain to the southeast of the Town of Woodstock. A Cu dispersal train extents south-southeastward from the Connell Mountain area for a distance of approximately 10 km onto the adjoining Millville (NTS 21 J/03) map area. This indicates that the dominant glacial dispersal direction in the Woodstock area is comparable to that observed in adjacent areas.

Le secteur cartographique de Woodstock (SNRC 21 J/04) est traversé par la faille de Woodstock, qu'on sait associée à une minéralisation d'Au–As–Sb dans le secteur cartographique de Fosterville (SNRC 21 G/13), au sud. On sait de plus que maintes venues minérales, principalement constituées de chalcopyrite et de minéraux connexes, proviennent de la partie du secteur cartographique de Woodstock à l'est de la faille. On a par conséquent réalisé l'échantillonnage de till dans le secteur au cours de 1999 en suivant la grille d'échantillonnage standard de deux kilomètres dans le voisinage immédiat de la faille, à l'est, de même qu'en suivant une variante de cette grille comportant un échantillonnage à tous les deux points de grille dans le secteur à l'ouest. Les résultats permettent de supposer que la minéralisation pourrait être rattachée à la faille de Woodstock sur sa longueur jusqu'au sud de la ville de Woodstock. Une minéralisation vraisemblablement associée à de petites failles parallèles ou transversales pourrait également être présente dans le secteur à l'ouest de la faille de Woodstock. Dans le secteur à l'est de la faille de Woodstock, la majorité des venues minérales connues semblent trop modestes à la surface pour produire des anomalies du till à l'échelle de l'échantillonnage. Une anomalie importante de Cu est cependant associée à des venues connues près du mont Connell, au sud-est de la ville de Woodstock. Une traînée de dispersion de Cu s'étend vers le sud-sud-est sur une distance d'une dizaine dekilomètres à partir du secteur du

† New Brunswick Geological Surveys Branch ordinary budget.

mont Connell jusqu'au secteur cartographique adjacent de Millville (SNRC 21 J/03). Cette traînée révèle que la direction prédominante de la dispersion glaciaire dans le secteur de Woodstock est comparable à celle observée dans les secteurs adjacents.

INTRODUCTION

In 1990, till geochemistry investigations were begun in west-central New Brunswick. Sampling in the New Brunswick part of the Forest City (NTS 21 G/12) map area (Figure 1) identified an area of elevated Au values (Seaman 1992) that were interpreted as part of a dispersal train from a source to the north (Seaman 1993b). Subsequent work in the adjoining Fosterville (NTS 21 G/13) map area (Figure 1) identified the source of the Au dispersal train as mineralization in the Poplar Mountain area, adjacent to the Woodstock Fault (Seaman 1993a, 1994b). Recent exploration in the Poplar Mountain area (Golden Ridge property) has revealed that the mineralization is associated with subvolcanic rocks along the Woodstock Fault zone (Freewest Resources Canada Inc. 1999). Consequently, in 1999 till geochemistry sampling was carried out in the New Brunswick part of the Woodstock (NTS 21 J/04) map area (Figure 1), immediately to the north of the Fosterville map area, to help assess the mineral resource potential adjacent to the Woodstock Fault in this area. This report summarizes the results of the work in the Woodstock map area. The complete geochemical data set and the related site location and geological information obtained during the course of this sampling project are presented in Seaman (2000b).

The Woodstock (NTS 21 J/04) map area lies adjacent to the Maine border in west-central New Brunswick (Figure 1), and comprises an area of approximately 606 km^2 in New Brunswick. The Saint John River flows from north to south near the eastern edge of the map area. An extensive network of Provincial, local and logging roads provides good access to most of the area.

GEOLOGIC ENVIRONMENT

Bedrock geology

The bedrock geology of the Woodstock map area was mapped at one-mile scale (1:63 360) by Anderson (1968). Subsequently, Venugopal (1979, 1981) conducted detailed quarter-mile (1:15 840 scale) mapping of the area overlying and to the east of the Woodstock Fault. Fyffe (1982) summarized the geology of the area at the scale of 1:250 000. The bedrock boundaries shown on Figure 2 are based on Fyffe (1982) and Venugopal (1979, 1981). Descriptions of the bedrock units are in Table 1, with updated unit designations (L.R. Fyffe, personal communication, 2000).

The Woodstock Fault is a major northeast-trending fault that separates the Matapedia Cover Sequence to the northwest, from the Miramichi Terrane to the southeast (Fyffe and Fricker 1987). The Matapedia Cover Sequence comprises interstratified limestone and slate of the Upper Ordovician to Lower Silurian Carys Mills Formation (OScm) and predominantly calcareous sandstone of the Silurian Smyrna Mills Formation (Ssm) (Figure 2). The latter formation contains a belt of red manganiferous iron-formation (Anderson 1968). In the Miramichi Terrane, the dominant bedrock unit comprises clastic sedimentary rocks of the Cambro-Ordovician Miramichi Group (ЄOm). This unit is intruded by six felsic stocks of Ordovician age, including the Benton granite (Obt) and the Gibson granodiorite (Ogi), and by numerous Devonian mafic dykes. Ordovician mafic volcanic rocks of the Oak Mountain Formation (Oom) lie between the Benton granite and the Woodstock Fault, in the south-central part of the map area. To the north of Woodstock is a second area of mafic volcanic rocks in a narrow fault block traversed by the Saint

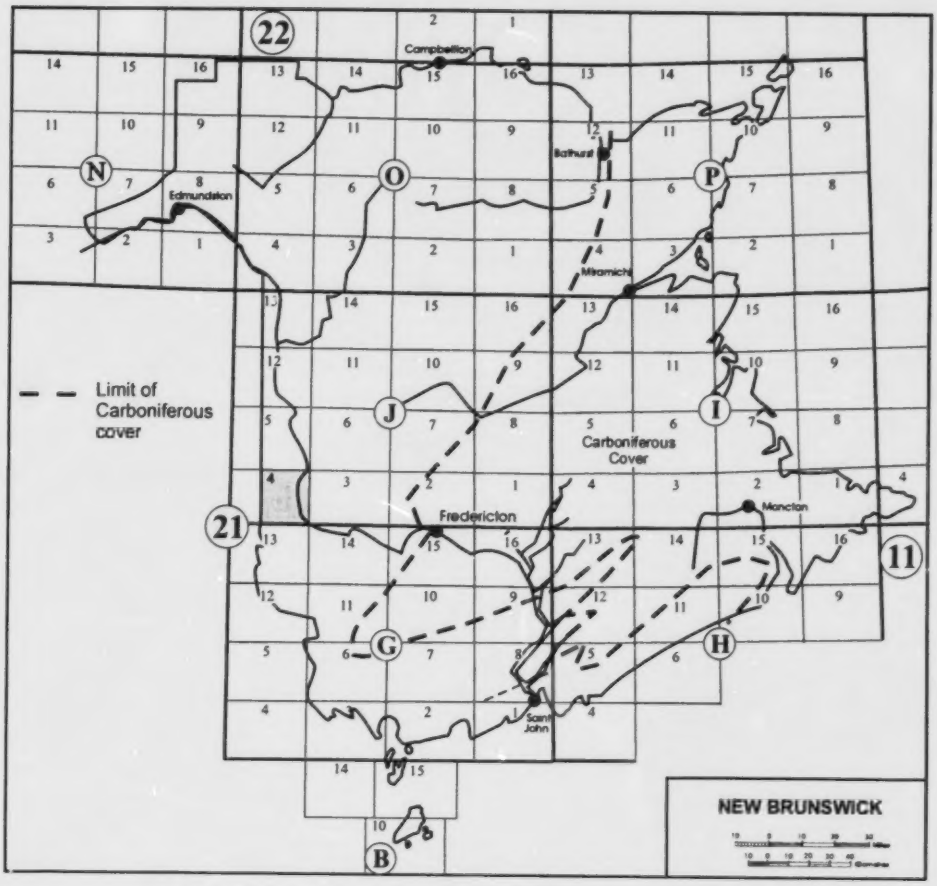


Figure 1. Location of the Woodstock (NTS 21 J/04) map area.

John River (Venugopal 1981). Although originally interpreted as Lower Devonian in age, these rocks are now thought to be of Silurian age and related to the Smyrna Mills Formation (L.R. Fyffe, personal communication, 2000). To the north of these, west of the Saint John River and unconformably overlying the Miramichi Group, are red, coarse clastic sedimentary rocks of the Carboniferous Carlisle Formation (Cc1).

Mineral occurrences

Forty-nine mineral occurrences are on record for the Woodstock area in the New Brunswick mineral occurrence database (Merlini 1999) (Table 2 and Figure 2). Only nine of these, which are Fe–Mn occurrences (locally with P or Cu) in the Smyrna Mills Formation, lie to the west of the Woodstock Fault. East of the fault, 34 are Cu occurrences (some with associated Pb, Zn, Au, Ag, Mo, Ba or W), three are Pb or Ba occurrences, and the remaining three are Fe or Mn occurrences. The details concerning these mineral occurrences are reported by Merlini (1999) and Thomas and Gleeson (1988) (only to the east of the Woodstock Fault for the latter).

Surficial geology

The surficial geology of the Woodstock map area was first investigated by Chalmers (1884, 1902) and was subsequently mapped in detail by Lee (1962). Finamore (1981) mapped the granular aggregate

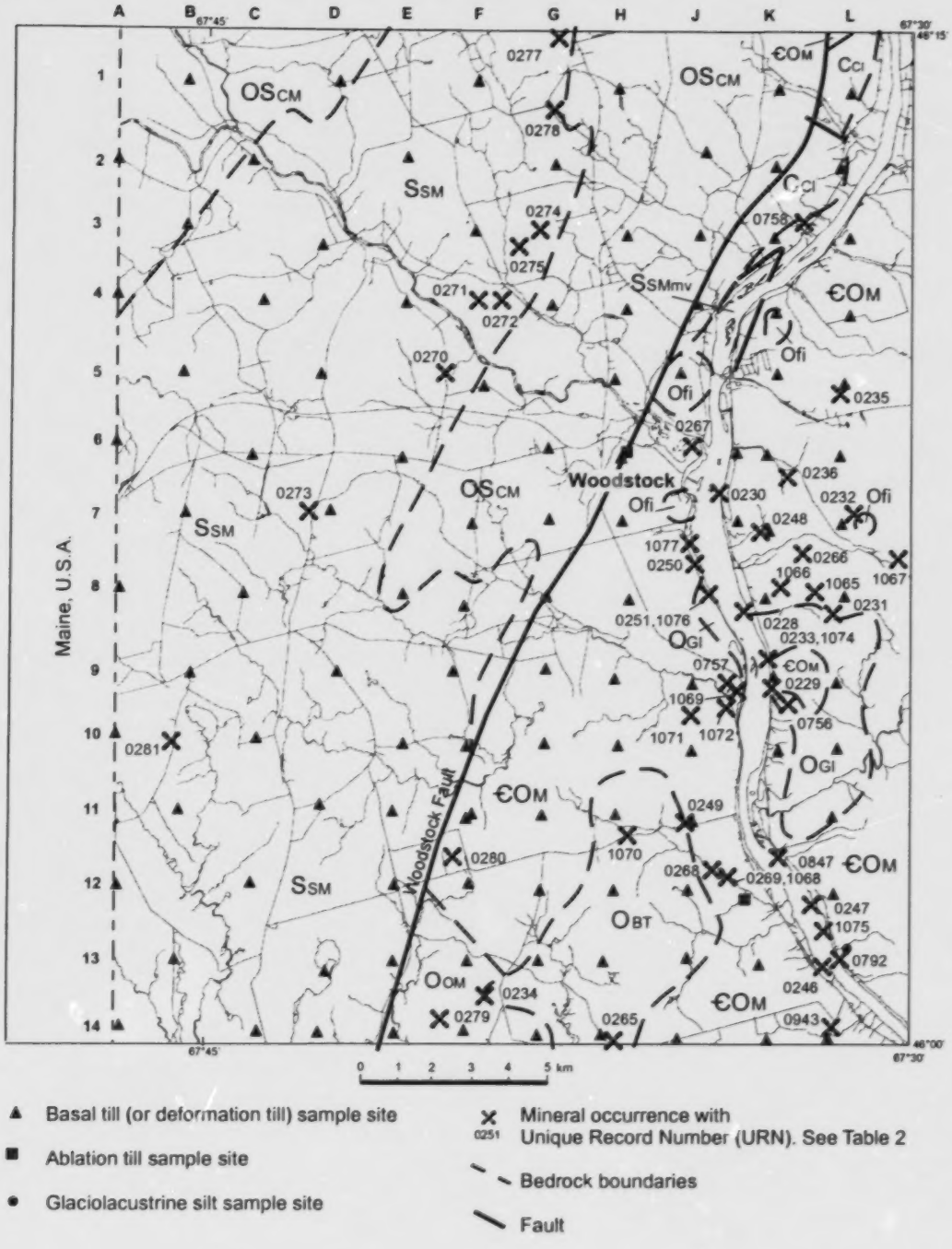


Figure 2. The 1999 till geochemistry sample sites in the Woodstock (NTS 21 J/04) map area, in relation to the bedrock geology and known mineral occurences.

Table 1. Table of Bedrock Formations

System	Group	Formation	Map Unit	Lithology
Carboniferous		Carlisle	Ccl	Red conglomerate, sandstone and shale.
Silurian	Perham	Smyrna Mills	SSMmv	Greyish green amygdaloidal mafic volcanic flows and hyaloclastite.
			SSM	Bluish grey and greyish green calcareous sandstone interbedded with dark grey lithic sandstone, light grey crystalline limestone and grey slate; minor red manganiferous slate.
Ordovician–Silurian	Matapedia	Carys Mills	OSCM	Bluish grey, thin-bedded limestone interstratified with grey slate; minor grey lithic limestone.
Ordovician		unnamed	Ofi	Small felsic intrusions: pinkish grey feldspar porphyry in the two bodies to the north of Woodstock; pinkish grey quartz–feldspar porphyry in the body to the south of Woodstock; light pinkish grey granodiorite in the small stock to the southeast of Woodstock.
		Benton Granite	OBT	Pinkish grey to greyish green, equigranular to subporphyritic granite.
		Gibson Granodiorite	OGI	Pinkish grey to grey, equigranular to subporphyritic granodiorite to quartz diorite; minor dykes of feldspar–quartz porphyry, diabase and intrusive breccia.
		Oak Mountain	OOM	Dark greyish green mafic volcanic flows, tuff and breccia.
Cambrian-Ordovician	Miramichi		COM	Grey and greyish green quartzite interbedded with olive-green slate and siltstone; grey and greyish green quartz wacke interbedded with greyish green and dark grey slate, light green siltstone and minor red micaceous sandstone, siltstone and slate; Devonian mafic dykes are common.

resources in the area. Rampton and Paradis (1981) synthesized the Quaternary geology of the area at a regional scale, which was subsequently summarized by Rampton *et al.* (1984).

The area is characterized by generally rolling bedrock topography, with local ridges and hills (Chalmers 1902). Glacial striae trends observed on bedrock surfaces by Chalmers (1884, 1902), Finamore (1981), Lee (1962), and Rampton and Paradis (1981) were reported as ranging from southeastward through to south-southwestward, with Finamore (1981) also reporting eastward to east-southeastward trends at a

Table 2. Mineral Occurrences in the Woodstock (NTS 21 J/04) Map Area

URN*	NAME	ELEMENTS
0228	Saint John River Gold	Au, Cu, Pb
0229	Upper Northampton Gold	Au, Cu, Pb, Zn
0230	Grafton	Au, Cu, Pb
0231	Upper Northampton	Au, Cu, Mo
0232	Connell Mountain	Au, Cu, Mo, Pb, Zn
0233	Upper Northampton Barite	Ba
0234	Oak Mountain	Ag, As, Au, Cu, Pb, Sb, Zn
0235	South Newbridge	Ba, Cu, Pb
0236	Wright Brook	Ag, Au, Cu, Pb, Zn
0246	Hillman Copper	Cu
0247	Tompkins	Ag, Cu, Pb, Zn
0248	Dominion 1	Ag, Au, Cu, Pb, Zn
0249	Dugan Road – East	Cu, W
0250	Bedell Farm & Poulles Farm	Ag, Cu
0251	Silvermaque	Cu
0265	Benton	Cu
0266	Connell Brook	Cu, Zn
0267	Woodstock Cu-Pb	Cu, Pb
0268	Lilly Brook Cu-Mo	Cu, Mo
0269	Lilly Brook Lead	Pb
0270	Plymouth	Fe, Mn
0271	North Hartford	Fe, Mn
0272	South Hartford	Fe, Mn
0273	Richmond Corner	Fe, Mn
0274	Sharpe Farm	Fe, Mn
0275	Moody Hill & Iron Ore Hill	Cu, Fe, Mn
0277	Wakefield – Area 2	Fe, Mn, P
0278	Maple Hill – Area 1	Fe, Mn, P
0279	Oak Mountain Iron	Fe, Mn
0280	Wickham Iron	Fe, Mn
0281	Union Corner	Fe, Mn
0756	Cobbler Sexton	Ag, Au, Cu, Pb, Zn
0757	Bull Creek No. 3	Au, Cu, Pb, Zn
0758	Britton Mine	Ag, Au, Cu, Pb
0792	Lower Northampton Copper	Cu, Pb
0847	Lower Northampton Copper – B	Ag, Cu
0943	Riceville	Cu
1065	Smart Farm	Au, Cu, Mo, W, Zn
1066	Monteith Farm	Cu
1067	Southeast Connell Mountain	Cu
1068	Lilly Brook Copper	Cu
1069	Interchange Copper	Cu
1070	Dugan Road West	Cu
1071	Bulls Creek 1	Cu, Zn
1072	Bulls Creek 2	Ag, As, Au, Cu, Zn
1074	Upper Northampton Barite	Ag, Ba, Pb
1075	Frazer & Briggs	Cu, Pb, Zn
1076	Wetmore Copper	Cu
1077	Peabody Farm	Fe

* Unique Record Number (from Merlini 1999)

couple of sites. Southeast- to south-southwest-trending striae were also observed during the course of this till sampling project.

The bedrock is generally overlain by a veneer (<0.5 m) or blanket (0.5–1.5 m) of basal till (Rampton and Paradis 1981). Our observations indicate that till thickness can vary significantly over very short distances. For example, site WS-E06 was excavated to a depth of 0.85 m, without hitting bedrock, in a roadcut section that exposed bedrock to the surface 2 m to the west and level with the base of the section 1 m to the east.

The basal till is dominantly an olive brown to yellowish brown, moderately to extremely compact lodgement till. Its texture is typically a gravelly sandy mud or sandy muddy gravel (after Folk 1968; see Seaman 2000b) or, in soil science terms, a clay loam or loam that is commonly gravelly or very gravelly (Agriculture Canada 1974). Significant thicknesses of basal meltout till and basal deformation till were identified at only two sites (WS-F11a and WS-H03, respectively). The meltout till was a yellowish brown, moderately loose to moderately compact (compactness increasing with depth), muddy sandy gravel (very gravelly sandy clay loam). The deformation till was a yellowish brown, moderately compact, slightly gravelly sandy silt (silt loam).

Lee (1962) mapped significant areas of rill wash in the northwest, southwest and northeast corners of the map area. He noted that this material "consists of a mixture of sand and stones and occurs in pockets or lenses along rill depressions in a broad area of sheetwash" (p. 3), with an average thickness of 1.2 m. However, of the 31 samples collected during this till sampling project from within the limits of Lee's rill wash units, 27 consisted of basal lodgement till, one consisted of deformation till (site WS-H03), and one consisted of moderately loose ablation till (site WS-H06a). At only two of the sample sites (WS-H05 and -J04) did the material consist of moderately loose to moderately compact material that might conform to Lee's description. However, both of these sites lie below the 100 m contour line in the Saint John River valley, and are thus more likely to have been wave washed during the late-glacial flooding of the Saint John River valley, or they could also be meltout till. While rill wash material is no doubt present in the area, it does not appear to occur as mappable units.

Ablation till is uncommon in the Woodstock map area. Finamore (1981) identified two small areas, one along Highway 540 to the north of grid point WS-C01 and the other along the Trans-Canada Highway east of grid point WS-J11. Ablation till was observed at a number of other locations during the course of this till sampling program, but most of the deposits appeared to be of limited extent. Ablation till was sampled at sites WS-H06a and -K12. The material at these two sites consisted of moderately loose, olive brown, silty sandy gravel (very gravelly sandy loam).

Glaciofluvial deposits are confined to the Saint John River valley and the valleys of some of its tributaries, such as Bulls Creek, Meduxnekeag River and Clarks Brook (Finamore 1981). During the present study, glaciolacustrine (or glacio-estuarine) silts were observed at levels up to about 100 m (as at site WS-K09) along the Saint John River valley. At site WS-L13, the material comprises a gravelly sandy silt (gravelly silt loam) that is interpreted as a reworked till, formed by wave action along the shore of the late-glacial water body ponded in the Saint John River valley.

TILL-PEBBLE LITHOLOGY

A sample of pebbles was collected from the till at each sample site. Nominal sample size was 100 pebbles of coarse gravel or larger size (approximately 1.5 cm or greater b-axis dimension). However, at sites where pebbles in the till were sparse, as few as 10 pebbles were collected, with a size as small as approximately 1 cm. The results of the till pebble lithology identifications for each site are summarized in Appendix 1 of Seaman (2000b).

A surprising result is the scarcity of calcareous clasts in the pebble samples. Calcareous slate and limestone comprise the principal lithotypes in the Carys Mills Formation, while calcareous sandstone, siltstone and slate, with minor limestone are found in the Smyrna Mills Formation (Fyffe 1982). Every sedimentary clast among more than 9000 pebbles examined was tested with 10% HCl. However, no limestone pebbles

were found, and calcareous sedimentary clasts were comparatively rare. Only three of the samples contain a significant percentage (>10%) of such clasts. At sites WS-B01 and -D01, both overlying the Carys Mills Formation, calcareous clasts comprise 18% of the total. The site with the highest concentration of calcareous sedimentary clasts (38%) is WS-K06, which overlies the generally non-calcareous Miramichi Group. This discrepancy may arise as a result of post-glacial leaching. Many of the calcareous sedimentary clasts comprise an outer rim of leached, non-reactive material, with a core of calcareous material. Many of the non-calcareous pebbles are similar in appearance to the leached rims, suggesting that they may be formerly calcareous pebbles that have been completely leached. The presence of so many calcareous pebbles at site WS-K06 suggests that the till in the area has considerable buffering capacity against leaching. This is confirmed by the geochemical analyses: the till sample from this site is extremely anomalous in Ca (2.21%, four times the next highest value obtained). The presence of two quartz–carbonate vein pebbles in the sample suggests that the bedrock in the vicinity may be enriched in calcium carbonate.

Since sedimentary rock types are predominant in the Woodstock map area, it is no surprise that pebbles of such rocks comprise more than 70% of the pebbles at most sites. What is surprising is that up to 33% of the pebbles at sites overlying the Carys Mills and Smyrna Mills formations consist of various igneous rock types, primarily volcanic. Some of these clasts are rounded and, therefore, were probably derived from conglomerates or preglacial gravels. However, most of the clasts are angular to subrounded in shape, suggesting derivation from bedrock by glacial action. Since the dominant glacial dispersal direction in west-central New Brunswick is toward the south-southeast (Seaman 2000a), the most probable source for these clasts is the mixed volcanic rock unit to the west of Presque Isle (>50 km distant) and the small intrusions between there and Woodstock (see Osberg *et al.* 1985). Support for this interpretation was found at site WS-H04, where the farm fencerow contained a boulder of distinctive Deboullie syenite from northern Maine (approximately 130 km to the northwest) in association with a number of erratic boulders of Silurian–Devonian felsic and mafic volcanic and intrusive rocks.

Despite the presence of two mafic volcanic units and a half dozen felsic intrusions in the area to the east of the Woodstock Fault, high percentages of igneous clasts (>40%) were found in only five of the pebble samples. For site WS-F14, on the Oak Mountain Formation, 45% of the clasts are of volcanic origin, primarily very angular to subangular mafic to intermediate volcanic clasts of probable local origin. The sample from site WS-H14 is the only one among the seven sites on the Benton Granite that contains a significant percentage of granitic clasts (32%, of which one is a subrounded granodiorite from a distal source). Under-representation of Benton Granite clasts in till was also noted in the adjacent Fosterville (NTS 21 G/13) map area (Seaman 1995). Seaman (1995) suggested that this could be due to one or a combination of: the low topography on the southern part of the stock; preglacial weathering of the granite that resulted in a source material composed primarily of sand and boulders; or varying basal ice conditions over different rock types. Since the northern part of the Benton stock is quite hilly, low topography can be eliminated as an explanation for the low granite content in the overlying till. In contrast, the sample from the northern site (WS-L09) on the Gibson stock is dominated by granitic clasts (98%), while that from the southern site (WS-L10) contains 40% granitic clasts. The probable cause for the difference between these two sites is that the till is thin at site WS-L09, with bedrock at the base of the section. The fifth sample with a high igneous rock component is from site WS-J05, which is centred over the small porphyry stock to the north of Woodstock; it contains 87% porphyry or granite clasts of probable local origin.

The lithology data suggests several possible revisions to the bedrock geology of the Woodstock map area. First, in the vicinity of the Town of Woodstock the trend of the Woodstock Fault probably lies

farther to the northwest than as mapped. The pebble sample from site WS-H06b consists of more than 50% Miramichi Group pebbles, while that from site WS-J04 consists of more than 25% Carlisle Formation conglomerate pebbles plus a number of subrounded pebbles that may have been derived from the conglomerate. If these sites lay on the fault trace, as plotted, they should not contain such large quantities of material derived from bedrock units to the east of the fault. Second, two bodies of volcanic rock may be present that have not been previously mapped. The sample from site WS-H07 contains 14% angular clasts of green–grey to green–brown, dacitic tuff and brown–grey dacitic crystal tuff. The sample from site WS-L08, just above the northeastern corner of the Gibson granodiorite, contains 18% very angular to angular clasts of grey, vesicular to amygdaloidal, pyritiferous basalt, with brown-weathering rinds. The angularity of the clasts suggests that bedrock sources lie in close proximity up-ice (to the north-northwest). Finally, the pebble samples from sites WS-L01 and -L02 contain no apparent clasts from the Carlisle Formation. This suggests that the Carlisle Formation may not be as extensive as mapped in this area, and that the Miramichi Group may be more extensive.

TILL GEOCHEMISTRY

Previous studies

Two previous regional till geochemistry surveys that included the Woodstock area have been carried out by the Geological Survey of Canada. Both of these projects involved sampling along roads at natural or man-made exposures. Consequently, their coverage of the area is not uniform.

Kettles and Wyatt (1986) conducted a reconnaissance geochemical survey of glacial deposits in west-central New Brunswick to provide data of use in assessing the effects of acid precipitation. They collected samples from 24 sites identified as till and one identified as glaciofluvial sediments. The clay fraction of the samples was analyzed for Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, U and Zn.

A more extensive regional till geochemistry survey was subsequently carried out in the southern Miramichi Zone and vicinity (Lamothe 1990, 1992). Lamothe (1990) includes geochemical data for 75 additional samples collected in the Woodstock map area and that from re-analysis of Kettles and Wyatt's (1986) samples. Results are reported for both clay fraction splits (<2μm) and silt-plus-clay fraction splits (<63μm). As, Co, Cr, Cu, Fe, Mn, Ni and Zn values are reported for all clay fraction samples, and Ag, F, Hg, Mo, Na, Pb, Sn, U and W values are reported for some. As, Au and Sb values are reported for all clay-plus-silt samples, and Mo values are reported for some.

Lamothe (1992) presents element distribution maps (based on percentiles) for Cu, Pb, Zn, Sn, W, U, Sb and Hg for the entire Miramichi Zone and adjacent areas and a map indicating the sites at which Au values exceeded 10 ppb. Cu was the only element for which values exceeded the 75th percentile. A 'head' of 90–95 percentile Cu associated with the mineral occurrences in the Connell Mountain area (in the vicinity of grid point WS-L07) is accompanied by a southeast to south-southeast-trending tail at the 75–90 percentile level. Two sites with elevated Au values (11 ppb, Lamothe 1990) are indicated, both a few km to the west of the Town of Woodstock.

Sampling and analytical procedures

In general, the sampling procedures for the Woodstock area followed previously established practices for till sampling on the standard 2 km grid. However, because mineral potential of the Smyrna Mills and Carys Mills formation sediments to the west of the Woodstock Fault was expected to be low, only every

second grid point was sampled, on an alternating basis (e.g., WS-A2, -A4, ... -B1, -B3, etc.), over these formations. Analytical procedures included the standard INAA (instrumental neutron activation analysis) package for Au plus 34 elements, ICP (inductively coupled plasma emission spectrometry) analysis for 20 elements, and analysis for Hg using cold vapour-atomic absorption spectrometry (AAS). One change from previous practice was to replace analysis for Sn by fusion-ICP with analysis for Bi, Ge, In, Se, Sn, Te and Tl by ICP-MS (ICP-mass spectrometry) analysis. Other details regarding sampling, sample preparation and analytical methods are presented in Seaman (2000b), along with a discussion of analytical reproducibility as indicated by the analysis of standard and duplicate samples.

Determination of anomalous values

The definition of an anomaly can be determined in a variety of ways (e.g., Rose *et al.* 1979). In this report, a value will be described as threshold anomalous if it is from 2 to 4 standard deviations (SDs) above the mean, anomalous if it is from 4 to 8 SDs above the mean, very anomalous if it is from 8 to 16 SDs above the mean, and extremely anomalous if it is 16 SDs or more above the mean. The use of statistical methods to determine anomalies is considered appropriate for reconnaissance geochemical surveys, such as that reported here, in which few anomalies are expected and the data sets have approximate normal distributions (Rose *et al.* 1979).

In this report the means and standard deviations used are based on refined data sets from which extreme values (values greater than 4 SDs above the mean for the raw data set) have been deleted. References to anomalies of Lamothe (1990) are based on mean and standard deviation values calculated by this author for only the 100 GSC sample sites in the Woodstock map area. It should be noted that Lamothe's (1990, 1992) data is not directly comparable to that obtained during the current project, because of significant differences in analytical methodology.

Distribution of anomalies

The distribution of anomalies in the Woodstock map area differs from that expected based on the distribution of mineral occurrences in the area. Whereas more than 80% of the recorded mineral occurrences lie to the east of the plotted position of the Woodstock Fault, slightly less than half of the till sample sites with anomalous concentrations of elements of economic significance lie in the same area.

The distribution of the elements will be discussed on an element by element basis, with comments regarding correlations with geology, known mineral occurrences or anomalies in Lamothe's (1990) data. Place names used to identify anomalous areas are from the Woodstock 1:50000 scale (NTS 21 J/04) topographic map, Edition 2. The place names are accompanied by the sample site numbers for the anomalous sites so that the location of the anomaly (with respect to roads, streams and bedrock units) can be identified on Figure 2. Mineral occurrence names and Unique Record Numbers (URNs) (Table 2) are from the "New Brunswick Computerized Mineral Occurrence Database" (Merlini 1999).

As: The most striking aspect of As distribution in the Woodstock map area is a band of elevated values [1 SD or more above the mean (>24.7 ppm)] occurring along the Woodstock Fault from the bottom of the map area to Woodstock. Within this band, and just to the west of the fault, there are anomalies to the east of Gidney Brook (site WS-D14; 73.8 ppm) and to the west of Woodstock (site WS-G07; 76.9 ppm), and threshold anomalies in the Bedell Settlement–Mapledale area (sites WS-F07, -F09 and -F10; 35.3 ppm, 38.8 ppm and 35.6 ppm, respectively). Lamothe's (1990) data includes two threshold anomalies within this band, one to the south of site WS-F07 and the other between sites WS-E13 and -F12. The anomaly

to the west of Woodstock (site WS-G07) may constitute an environmental concern, as the site lies within a subdivision.

Threshold anomalies for As also occur as spot occurrences at Green Road (site WS-B09; 34.8 ppm) and Blowdown (site WS-B13; 46.2 ppm) to the west of the Woodstock Fault, and at Sharps Mountain (site WS-K04; 34.6 ppm) to the east. The occurrence at Blowdown corresponds with an As anomaly in Lamothe's (1990) data.

Au: Most of the samples collected from the Woodstock map area returned a non-detectable value (<2 ppb) for Au. As a result, the calculated threshold level is only 3 ppb, half that reported for the west half of the adjacent Millville (NTS 21 J/03) map area (Seaman 1998).

In the area to the west of the Woodstock Fault, there is a spot Au anomaly (7 ppb) to the west of Richmond Corner (site WS-C06) and an area of threshold to anomalous Au in the Elmwood–Debec area (sites WS-C10, -D09 and -D11; 7 ppb, 7 ppb and 4 ppb, respectively). These last three sites lie to the south of the Richmond Corner Fe–Mn occurrence (URN 0273) and to the east of the similar Union Corner occurrence (URN 0281). This suggests a possible correlation of the Au with the manganiferous iron-formation. The weathered bedrock sample from Rosedale (site WS-K01) also returned an anomalous value (5 ppb). Au was not detected in the vicinity of the two sites identified by Lamothe (1990, 1992).

To the east of the Woodstock Fault there are anomalies at Sharps Mountain (site WS-K04; 6 ppb) and on the Dugan Road (site WS-J11; 6 ppb). The latter site is just to the east of the Dugan Road East Cu–W occurrence (URN 0249), suggesting a correlation with that occurrence. There is also a threshold anomaly (3 ppb) immediately to the south, at site WS-J12. Threshold anomalies are also present at sites WS-K07 and -L07 (4 ppb each) in the vicinity of the Dominion No. 1 (URN 0248), Connell Brook (URN 0266), Connell Mountain (URN 0232) and Southeast Connell Mountain (URN 1067) mineral occurrences. Similar Au levels were reported for nearby sites in the Millville map area (Seaman 1999b; sites MV-A07, -A08 and -A10). Au is reported in association with the Cu and other elements at the Dominion No. 1 and Connell Mountain occurrences, so these or related occurrences probably constitute the source.

It should be noted that, as a consequence of the nugget effect, individual analyses for Au should not be taken as absolute. For example, GSC standard LKSD-1 has an expected value (1 SD range) of 5 ± 2 ppb (Lynch 1990). During the course of DNRE till sampling projects over the past decade, 31 splits of this standard have been analysed by Activation Laboratories Limited of Ancaster, Ontario, with 23% returning values of less than 3 ppb and 19% returning values of more than 7 ppb (maximum of 34 ppm). Standards LKSD-2 and LKSD-3, with expected values of 3 ± 2 ppb (Lynch 1990), returned values more than 5 ppb for 16% and 25%, respectively, of the splits analysed (32 each, with maximum values of 12 ppb). Therefore, there is a significant probability that at least some of the 3 ppb to 7 ppb threshold to anomalous values reported above reflect analytical perturbations rather than actual anomalies.

Bi: There are only two Bi anomalies in the Woodstock map area. One is at site WS-L07 (0.4 ppm), which is close to the Connell Mountain (URN 0232) mineral occurrence. The second is a threshold anomaly in the sample from the basal meltout till to the south of the Sherwood Lakes on Debec Stream (site WS-F11a; 0.3 ppm).

Co: Co reaches threshold anomalous levels in basal till in only two areas, at Green Road (site WS-B09; 32 ppm) and in the Blowdown area (sites WS-B13 and -C12; 34 and 33 ppm, respectively), both to the

west of the Woodstock Fault. Lamothe's (1990) data contains two threshold Co anomalies, both of which lie between the above two areas (though only average values were obtained in this study for sites WS-B11 and -C10). Interestingly, Co was at threshold levels (for basal till) in both of the weathered bedrock samples (from sites WS-A10 to the north of Union Corner and WS-K01 at Rosedale; 30 and 31 ppm, respectively).

Cu: Despite the number of reported Cu occurrences in the Woodstock map area, there is only one significant anomaly, encompassing three sample sites. The northernmost site (WS-L07; 401 ppm) lies proximal to the Connell Mountain occurrence (URN 0232) and is extremely anomalous. The two sites to the south (sites WS-L08 and -L09) are threshold anomalous to anomalous (85 ppm and 105 ppm, respectively). These sites lie to the southeast of a number of Cu occurrences. All three sites lie within the area of the dispersal train evident in Lamothe's (1992) plot of Cu distribution, and close to the two anomalous sites in Lamothe's (1990) data that mark the head of the dispersal train.

In addition to the above, threshold Cu anomalies are present in the Blowdown area (sites WS-B13 and -C12; 83 and 66 ppm, respectively), and in the deformation till at Jacksonville (site WS-H03; 59 ppm).

Fe: There are few Fe anomalies in the Woodstock map area. However, the presence of iron-formation in the Smyrna Mills Formation is evident in generally above average Fe values at sites to the west of the Woodstock Fault, and generally below average values to the east. Threshold anomalies are present in the Blowdown area (sites WS-B13 and -C12; 6.10 and 6.01%, respectively) and north of Campbell Settlement (site WS-E06; 6.10%). The latter site is close to the two sites for which Lamothe (1990, 1992) reported elevated Au values, again suggesting an association of Au with the manganiferous iron-formation.

Site WS-J04 near Upper Woodstock is anomalous in Fe (8.18%). As noted above, the pebble sample from this site contains a significant percentage of clasts derived from the Mississippian Carlisle Formation redbed sequence. These haematitic sediments comprise the probable source for the anomalous Fe at this site. A small dispersal train of Fe, defined by the contour line for the mean Fe value (4.51%), extends from site WS-J04 for about 6 km toward the southeast to south-southeast (encompassing sites WS-K05, -L06 and -L07).

As with Co, both weathered bedrock samples (from sites WS-A10 and -K01) returned threshold anomalous values (6.20% and 6.07%, respectively).

Hg: The most significant Hg anomaly is at Blowdown (site WS-B13; 161 ppb). Next is in the ablation till along Lilly Brook (site WS-K12; 138 ppb). This anomaly may relate to the Lilly Brook Cu–Mo, Pb and Cu occurrences (URNs 0268, 0269 and 1068) which lie within 1.3 km up the Lilly Brook valley.

Threshold anomalies are in the Hovey Hill–Green Road area (sites WS-A08 and -B09; 73 and 92 ppb, respectively), to the east of Gidney Brook (site WS-D14; 79 ppb), along the Woodstock Fault to the north of Teeds Mills (site WS-G08; 73 ppb), in the deformation till at Jacksonville (site WS-H03; 73 ppb), and to the south of Sharps Mountain (site WS-K-05; 78 ppb). The weathered bedrock sample from north of Union Corner (site WS-A10) also returned a threshold value for Hg (77 ppb). None of the Hg anomalies correspond with those in Lamothe's (1990) data.

Mn: As with Fe, there are few Mn anomalies in the Woodstock map area. However, the presence of the manganiferous iron-formation in the Smyrna Mills Formation is evident in above average Mn levels over

the formation. It is also evident in the comparatively high average value for Mn in the area, 1219 ppm as opposed to only 845 ppm for the adjacent Millville (NTS 21 J/03) map area.

There is no direct correlation with Fe. Of the five threshold anomalies that are present, only the one at Blowdown (site WS-B13; 2595 ppm) is coincident with an Fe anomaly. The others are at Green Road (site WS-B09; 2494 ppm), Plymouth (site WS-F05; 2745 ppm), in the basal meltout till to the south of the Sherwood Lakes (site WS-F11a; 2576 ppm) and over the southern part of the Gibson Granodiorite (site WS-L10; 2880 ppm). The threshold anomaly at Plymouth is to the south of the Hartford Fe–Mn occurrences (URNs 0271 and 0272) and east of the Plymouth occurrence (URN 0270), and may relate to one or more of these occurrences. There is no correlation with the Mn anomalies in Lamothe's (1990) data.

Mo: Detectable Mo (by ICP) was present in only six of the samples collected from the Woodstock map area. Four of these were in the Green Road–Blowdown area [sites WS-B09 (3 ppm), -B11 (2 ppm), -B13 (3 ppm) and -C12 (2 ppm)]. Two of the six anomalies in Lamothe's (1990) data lie within this area. Mo values of 2 ppm were also obtained for one of the field duplicate samples from site WS-E06 north of Campbell Settlement and for the basal meltout till sample from site WS-F11a to the south of the Sherwood Lakes.

Ni: Three threshold basal till Ni anomalies are present in the Woodstock map area. These are at Blowdown (site WS-B13; 98 ppm), to the east of Gidney Brook (site WS-D14; 93 ppm) and to the west of Woodstock (site WS-G07; 92 ppm). Lamothe's (1990) data indicates threshold Ni anomalies in the vicinity of Blowdown and at a couple of sites to the north.

As with both Co and Fe, the two weathered bedrock samples from sites WS-A10 and -K01 returned threshold level values for Ni (102 ppm and 106 ppm, respectively).

Pb: Pb differs from the majority of the elements discussed here in that all of the anomalies lie to the east of the Woodstock Fault. Most significant is the very anomalous occurrence at Sharps Mountain (site WS-K04; 75 ppm). The threshold anomaly at Connell Mountain (site WS-L07; 29 ppm) is probably related to the Connell Mountain occurrence (URN 0232), that at Bulls Creek (site WS-J09; 28 ppm) to the Bulls Creek No. 3 occurrence (URN 0757), that in the ablation till along Lilly Brook (site WS-K12; 34 ppm) to the Lilly Brook Pb occurrence (URN 0269) and that at Riceville (site WS-L14; 31 ppm) possibly to the Riceville Cu occurrence (URN 0943). Mineral occurrences are not known in the vicinities of the other threshold anomalies at Estabrooks Mountain (site WS-H07; 28 ppm), to the south of Poverty Peak (site WS-G10; 27 ppm) or in the basal meltout till to the south of the Sherwood Lakes (site WS-F11a; 29 ppm). These anomalies may relate to mineralization along the Woodstock Fault to the northwest of the sites.

REEs: Rare earth element (REE) concentrations were assessed by grouping together all of the nine rare earth elements for which analytical data was obtained (Ce, Eu, La, Lu, Nd, Sm, Tb, Y and Yb). The values for each element were normalized by dividing by the mean value for that element, and then the nine normalized values for each sample were summed (giving an average value of 9.0 for the sum of the normalized values). One anomalous site and four threshold anomalous sites were identified. The anomalous site was southeast of Jackson Falls (site WS-C02; sum = 14.38). The threshold anomalies are present north of Union Corner (site WS-A10; sum = 11.86), east of Gidney Brook (site WS-D14; sum = 12.67), at Rosedale (site WS-K01; sum = 13.17) and at Bulls Creek (site WS-J09; sum = 11.93). The weathered bedrock samples from sites WS-A10 and -K01 gave similar values to those obtained for the till at the

same sites (sums of 12.35 and 13.38, respectively), indicating that in at least these two areas the underlying bedrock is the source for the anomaly.

S: Threshold anomalies of S (0.02%) occur at a number of sites in the Woodstock map area: at Hovey Hill and north of Union Corner (sites WS-A08 and -A10, respectively); at Blowdown (site WS-B13); at Elmwood (site WS-C10); near Belleville (site WS-D03); east of Gidney Brook (site WS-D14); in the basal meltout till to the south of the Sherwood Lakes (site WS-F11a); north of Hartford (site WS-F03); near the west end of Lilly Brook (site WS-H11); to the south of Grafton Hill (site WS-J07); and over the Gibson Granodiorite (sites WS-L09 and -L10).

S is anomalous in the deformation till at Jacksonville (site WS-H03; 0.04%) and at the adjacent site at Upper Woodstock (site WS-J04; 0.03%), and very anomalous at Sharps Mountain (site WS-K04; 0.05%). It is also anomalous in the ablation till along Lilly Brook (site WS-K12; 0.03%). The latter anomaly probably relates to the three Lilly Brook sulphide occurrences (URNs 0268, 0269 and 1068) upstream along the brook.

Sb: Threshold anomalies for Sb occur at three adjacent sites in the Blowdown area (sites WS-A14, -B13 and -C12; 2.3 ppm, 2.9 ppm and 2.3 ppm, respectively). Lamothe's (1990) data contains a threshold anomaly in this area. Another threshold anomaly is present near Campbell Settlement (site WS-E06). This site lies close to one of Lamothe's (1992) sites with elevated Au values.

A belt of elevated Sb values in excess of one standard deviation above the mean (1.8 ppm) lies over the mapped trace of the Woodstock Fault from the southern edge of the map area north to Mapledale (site WS-F09). Sb is threshold anomalous at Mapledale (2.3 ppm), very anomalous 2 km to the south (site WS-F10; 5.9 ppm), and again threshold anomalous at the three sites between Wickham and Oak Mountain (sites WS- F12, -F13 and -F14; 2.9 ppm, 2.4 ppm and 2.7 ppm, respectively). As noted above, the samples from sites WS-F09 and -F10 also contain threshold anomalous As. Lamothe's (1990) data includes two threshold anomalies within the belt of elevated Sb values. This belt of elevated Sb values may comprise a southward-trending dispersal train. However, if so, anomalous Sb would be expected at sites WS-F11a and F11b: this was not observed. Another possibility is that the belt represents only short-distance dispersal from mineralization along much of the length of the Woodstock Fault in this area. Given that the dispersal trains in adjacent areas both to the south and the east have prominent southeast to south-southeast trends, the latter interpretation is preferred.

The Oak Mountain mineral occurrence (URN 0234), which lies just to the east of the lower part of the belt of elevated Sb values, comprises quartz float that is anomalous in Sb and other elements (Thomas and Gleeson 1988; Seaman 1994a). Based on the results noted above, it appears that the Oak Mountain float is probably related to Sb mineralization associated with the Woodstock Fault. The most probable source is in the vicinity of Wickham, where bedrock similar to that at the Au–As–Sb occurrence at Poplar Mountain has been observed (M.J. McLeod, personal communication, 2000).

Se: There are four threshold Se anomalies in the Woodstock map area. These are at Hovey Hill (site WS-A08; 1.1 ppm), Blowdown (site WS-B13; 1.2 ppm), east of Gidney Brook (site WS-D14; 1.2 ppm) and in the basal meltout till to the south of the Sherwood Lakes (site WS-F11a; 1.4 ppm).

U: Unlike the Millville map area, where U anomalies are associated with the granitic Pokiok Batholith, there are no U anomalies associated with the half dozen felsic stocks to the east of the Woodstock Fault.

U is threshold anomalous at site WS-B11 (3.4 ppm) to the east of Union Corner and north of Blowdown. This site lies to the west of an anomalous site in Lamothe's (1990) data. The weathered bedrock from the site to the north of Union Corner (site WS-A10) returned a threshold value for U (3.5 ppm), suggesting that the source is local.

The major U anomaly in the Woodstock map area is to the east of Gidney Brook, where the sample from site WS-D14 returned a very anomalous value (7.8 ppm).

W: There are no major W anomalies in the Woodstock map area, but there are a number of threshold anomalous occurrences (2 to 3 ppm). Two of these, to the south of Union Corner (site WS-A12) and at Irish Settlement (site WS-B07), lie close to anomalous sites in Lamothe's (1990) data. To the west of the Woodstock Fault, the other threshold anomalies are at Limestone (site WS-E12), west of Woodstock (site WS-G06) and in the Jacksonville area (sites WS-H03 and -J02).

To the east of the Woodstock Fault, the threshold anomalies are near Grafton (site WS-K05), on Estabrooks Mountain (site WS-H07), near the Dominion No. 1 mineral occurrence (URN 0248) (site WS-K07), in the Bulls Creek area (sites WS-H10 and -J09), east of Lower Northampton (site WS-L11), south of Speerville (site WS-G12) and at the east end of Benton Ridge (site WS-K14).

Zn: Zn is another of the elements with no major anomalies in the Woodstock map area. In addition, none of the threshold anomalies correlate with any of the known Zn occurrences. Basal till threshold anomalies are present at Hovey Hill (site WS-A08; 113 ppm), northeast of Blowdown (site WS-C12; 97 ppm), in the Jacksonville area (sites WS-H03 and -J03; 100 ppm and 96 ppm, respectively) and at Sharps Mountain (site WS-K04; 109 ppm). Threshold Zn levels were also returned for the weathered bedrock sample from Rosedale (site WS-K01; 97 ppm) and for the ablation till along Lilly Brook (site WS-K12; 113 ppm). There is no apparent correlation with the three threshold anomalies in Lamothe's (1990) data.

Significant multi-element anomalies

As is evident in the above listings of the distribution of anomalies for individual elements, there are several multi-element anomalies in the Woodstock map area. The most significant of these are discussed below.

Green Road: As noted above, the basal till sample from Green Road (site WS-B09) is very anomalous in Mo, and threshold anomalous in As, Co, Hg and Mn. In addition, it is also anomalous in Tl (0.21 ppm) and threshold anomalous in Ba (630 ppm) and Te (0.4 ppm). This site lies close to the straight line joining the Richmond Corner (URN 0273) and Union Corner (URN 0281) Fe–Mn occurrences, which suggests the possibility that the anomalies relate to the presence of manganiferous iron-formation in the vicinity.

Blowdown: Site WS-B13 at Blowdown is one of the most anomalous sites in the Woodstock map area. As noted above, the sample is very anomalous in Hg and Mo, and threshold anomalous in As, Co, Cu, Fe, Mn, Ni, S, Sb and Se. It is also threshold anomalous in Te (0.4 ppm) and Th (13.8 ppm). Site WS-C12, to the northeast, is anomalous in Mo and threshold anomalous in Al (10.70%), Ba (600 ppm), Be (3 ppm), Co, Cu, Fe, K (2.92%), Rb (149 ppm), Sb, V (142 ppm) and Zn, while site WS-A14, to the southeast, is threshold anomalous in Sb. The pebble samples from all three sites are dominated by clasts of local derivation (>90%), which suggests that the bedrock source for the anomalies may be proximal. The three sites lie along a line that is subparallel to the Woodstock Fault, that is known to be associated with Sb

mineralization to the south at Poplar Mountain. This suggests that there may be a mineralized splay of the Woodstock Fault in the Blowdown area.

East of Gidney Brook: The sample from site WS-D14 is very anomalous in U, anomalous in As, and threshold anomalous in Cs (10 ppm), Hg, Ni, S, Se and REEs. As at Blowdown, the pebble sample from this site is dominated by clasts of local derivation, suggesting a local source for the anomalies. This site lies about 1.5 km to the west of the Woodstock Fault, and therefore the mineralization is possibly related to the faulting.

Jacksonville–Upper Woodstock: The deformation till at site WS-H03 near Jacksonville is similar in colour and texture to the basal lodgement till at site WS-J02. Geochemically, the values obtained for the deformation till sample correspond (within 1 standard deviation) to values obtained at one or more of the five adjacent basal lodgement till sites (WS-G02, -G04, -H04, -J02 and -J03) for 86% of the elements. Therefore, the values obtained for the deformation till sample are considered to be comparable to those that would be obtained for a basal lodgement till in the immediate area.

As noted above, the sample from site WS-H03 is anomalous in S and threshold anomalous in Cu, Hg, W and Zn. It is also anomalous in Sr (131 ppm) and threshold anomalous in Ca (0.55%) and P (0.088%). The sample from site WS-J04 near Upper Woodstock is extremely anomalous in P (0.301%); anomalous in Cs (12 ppm), Fe and S; and threshold anomalous in Br (17.4 ppm) and Tl (0.12 ppm). The presence of straight, southeast-trending stream valleys in the area suggests that there may be minor faults in the area that are perpendicular to the Woodstock Fault. The anomalies in the Jacksonville–Upper Woodstock area could relate to such faults.

Sharps Mountain: The sample from site WS-K04 is very anomalous in Pb and S, anomalous in Au, and threshold anomalous in As and Zn, as well as Te (0.4 ppm) and Th (13.6 ppm). The sample from site WS-K05, to the south, is threshold anomalous in Hg, Pb, S and W, as well as Nd (39 ppm) and Th (13.0 ppm). There are several possible sources for the anomalies. Site WS-K04 lies approximately 2.5 km to the south to south-southwest of the former Britton Mine (URN 0758), a Ag–Au–Cu–Pb occurrence, so the anomalies could reflect glacial dispersal down the Saint John River valley from that occurrence. In addition, the sites lie to the southeast of both the Woodstock Fault and the fault-bounded block underlain by mafic volcanic rocks, either of which could be associated with mineralization. Site WS-K04 is also on the trend of the anomalies at Jacksonville and Upper Woodstock, and could be associated with a southeast-trending cross fault. Finally, the sites lie near the margin of one of the small felsic intrusions in the Woodstock area, so the anomalies could represent mineralization associated with emplacement of the intrusion. The presence of the anomalies at sites WS-K04 and -K05 may portend future environmental concerns, as the sites lie to either side of a developing subdivision.

Connell Mountain: The sample from site WS-L07, situated just to the southwest of the Connell Mountain Au–Cu–Mo–Pb–Zn occurrence (URN 0232), returned an extremely anomalous value for Cu, an anomalous value for Bi, and threshold values for Au, Pb, Th (13.2 ppm) and Ti (0.48%). Again, the preponderance of the clasts in the pebble sample are of local derivation (90%), suggesting that the Connell Mountain occurrence or a related occurrence in the area comprises the source for the anomalies.

Sherwood Lakes: Since it differs from basal lodgement till only in its mechanism of subglacial deposition, the basal meltout till from site WS-F11a to the south of the Sherwood Lakes does not differ significantly

in texture or colour from the basal lodgement till at nearby sites. It is the same colour as the basal lodgement till at sites WS-E10 and -F11b, and is similar in texture to the lodgement till at sites WS-E12 and -G12. Geochemically, the values obtained for the basal meltout till sample correspond (within 1 standard deviation) to values obtained at one or more of the nine adjacent basal lodgement till sites (WS-E10 to -E12, -F10 to -F12, and -G10 to -G12) for 86% of the elements. The exceptions are Mo, which is anomalous at site WS-F11a, and Bi, Mn, P (0.089%), Pb, S, Se and Te (0.4 ppm), which are threshold anomalous. Ge (0.33 ppm) and Tl (0.13 ppm) are also threshold anomalous in the basal meltout till. The anomalies at this site present a conundrum, as the sample from the basal lodgement till at site WS-F11b, a mere 150 m distant, has sub-threshold values for all elements. The same basic rock types are found in the pebble samples from both sites, though that from the meltout till site contains a somewhat greater proportion of local clasts (83% *vs* 72%). This suggests that the basal meltout till anomalies may represent local mineralization, perhaps associated with the nearby Woodstock Fault, whereas the values in the basal lodgement till may relate to more distal bedrock sources. As noted above, neither of the WS-F11 samples contain elevated Sb values, unlike the samples from the sites to the north and south.

Comparisons of different sample media

Ablation till: The values obtained for the ablation till sample from site WS-H06a at Woodstock correspond (within 1 standard deviation) to values obtained at one or more of the eight adjacent basal till sites (WS-G06, -G07, -H05 to -H07, and -J05 to -J07) for all of the elements. The values obtained for the ablation till sample from site WS-K12 near Lilly Brook correspond to values obtained at one or more of the six adjacent basal till sites (WS-J11 to -J13, -K13, -L11 and -L12) for 86% of the elements. The exceptions at this site were Br, Ce, Hg, Pb, S and Zn, which were enriched in the ablation till, and K, which was depleted. These exceptions may relate to the nearby mineral occurrences in the Lilly Brook valley (URNs 0268, 0269 and 1068).

These results suggest that, in this area, ablation till may serve as a proxy sample medium for basal till when the latter type of material is not readily available for sampling.

Glaciolacustrine silt: The values obtained for the glaciolacustrine silt sample from site WS-K09-1 north of Northampton correspond (within 1 standard deviation) to values obtained at one or more of the eight adjacent basal till sites (WS-J09, -J10, -K08, -K09-2, -K10, and -L08 to -L10) for 94% of the elements. In contrast, the values obtained for the sample of wave reworked till from site WS-L13 correspond to values obtained at one or more of the six adjacent basal till sites for only 71% of the elements. The six adjacent sites are WS-K13, -K14, -L12, and -L14 from the Woodstock map area, and MV-M12 and -M13 from the adjacent Millville map area.

In comparison to the till samples, the glaciolacustrine silt sample contains detectable Ag (0.5 ppm) and anomalous Hf (17 ppm), and is depleted in Pb. The depletion in Pb is not a surprise, since the silt would comprise material derived from much of the upper Saint John River drainage basin, whereas the tills are of comparatively local derivation, and thus influenced by the Pb mineral occurrences in the vicinity (URNs 0228 and 1074). The elevated value for Ag may not be significant, since it is just above the detection limit of 0.4 ppm. Hf is also anomalous in the reworked till sample (16 ppm). However, Hf values at this level or higher are reported for tills in adjoining map areas (Balzer 1992; Seaman 1999a, 1999b), so such values are not out of line in the drainage basin context represented by glaciolacustrine sediment samples. In comparison to the till samples, the reworked till sample is depleted in Al, Ba, Co, Cs, Fe, K, La, Rb, Sb, Sc, Th, V and Zn. While some of these elements are highly mobile (e.g., K, Rb,

Zn), others are relatively stable (e.g., Al) and would not be expected to be depleted in the shoreline environment. These results suggest that glaciolacustrine silt and wave-reworked till should be avoided in till sampling programs in this area, as the results obtained may not be comparable to those of the tills.

Weathered bedrock: In a direct comparison, the values obtained for the weathered bedrock samples from north of Union Corner (site WS-A10; Smyrna Mills Formation) and from Rosedale (site WS-K01; Carys Mills Formation) are distinctly different. Only 47% of the values obtained correspond (within 1 standard deviation) between the two samples. However, when compared to the results for the till samples from the five sites in the vicinity of each weathered bedrock site (sites WS-A08, -A10a, -A12, -B09 and -B11; and sites WS-J02, -K01-1, -K02, -L01 and -L02; respectively), strong similarities become evident. Both weathered bedrock samples are enriched in Al, Fe, K, Mg, Ni, V and Y with respect to the surrounding till. They are also enriched in Bi, Co, Cr, Eu, Lu, Nd, Sc, Sm, Te, Y and Yb, and depleted in Sr, with respect to most of the till samples from surrounding sites.

As noted above, the till samples from the same grid points as the weathered bedrock samples are threshold REE anomalies, indicating that local bedrock material has been incorporated in the till. However, most of the other elements are not associated with anomalous levels in the till samples. Therefore, weathered bedrock cannot be recommended as a suitable sample medium as an alternative to basal till in a till sampling program.

GLACIAL DISPERSAL

As noted above, the presence of igneous rock clasts in till samples obtained from the area overlying the Smyrna Mills and Carys Mills formations probably indicates generally southeastwards dispersal from rock units in the vicinity of Presque Isle, Maine, 50 km or more distant from the Woodstock map area. In work from adjacent areas Seaman (2000a) has identified early east-southeastward glacial dispersal followed by south-southeastward dispersal. Together these two directions would combine to form an apparent overall southeastward-trending, long distance dispersal pattern.

Large-magnitude, south-southeastward-trending dispersal trains have been reported from map areas adjacent to the Woodstock map area. In the Millville (NTS 21 J/03) map area to the east, a 27 km long, red till dispersal train is present with this trend, and a 23 km long Au dispersal train of similar trend is present in the Fosterville (NTS 21 G/13) and Forest City (NTS 21 G/12) map areas to the south (Seaman 2000a). However, in the Woodstock map area, the identifiable dispersal trains are shorter. As noted above, a 6 km long Fe dispersal train extends south-southeastward from site WS-J04. Also, Cu is dispersed south-southeastward from the Connell Mountain area onto the Millville map area for a total distance of approximately 10 km. Therefore, although shorter, the dominant dispersal direction in the Woodstock map area is most probably accordant with that observed in the adjacent map areas.

CONCLUSIONS

1. Most of the mineral occurrences identified in the New Brunswick Computerized Mineral Occurrence Database (Merlini 1999) are not directly reflected by anomalies in the till samples. This suggests that most of the occurrences have too little surface exposure to be reflected by a regional till geochemistry survey such as this one.

2. The mineralized float at Oak Mountain (URN 0234) was probably derived from mineralization associated with the Woodstock Fault to the north to northwest. The most probable source is in the vicinity of Wickham.

3. The number of anomalous sites to the west of the Woodstock Fault, in particular the multi-element anomalies at Green Road and Blowdown, east of Gidney Brook and at Jacksonville, suggests that the Smyrna Mills and Carys Mills formations may have greater mineral potential than previously thought. These are possibly related to splays of the Woodstock Fault.

4. The dominant direction of glacial dispersal in the Woodstock map area was probably toward the south-southeast, as in adjacent map areas. Therefore, the bedrock sources for the till anomalies most likely lie to the north-northwest of the till sample sites. Since most of the pebbles in the tills are of local derivation, the bedrock sources for the anomalies are also most likely local.

ACKNOWLEDGEMENTS

Tamara Holmes assisted with till sampling during the summer of 1999. Gerry Johnson assisted with the sampling during the fall. Both were involved with cutting the pebble samples for lithological identification. Preparation of the samples for shipment to the analytical lab and grain size analyses were performed by Rex Boldon. Les Fyffe identified the exotic pebbles in the samples.

The figures were prepared by Terry Leonard. The paper was critically reviewed by Les Fyffe and Malcolm McLeod, and approved for publication by Les Fyffe, Manager of Geological Surveys South.

REFERENCES

AGRICULTURE CANADA 1974. The system of soil classification for Canada. Canada Department of Agriculture, Publication 1455, 255 p.

ANDERSON, F.D. 1968. Woodstock, Millville, and Coldstream map-areas, Carleton and York counties, New Brunswick. Geological Survey of Canada, Memoir 353, 69 p.

BALZER, S.A. 1992. Quaternary geology and dispersal patterns of the Canterbury area, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 92-5, 192 p.

CHALMERS, R. 1884. Report on the surface geology of western New Brunswick with special reference to the area included in York and Carleton counties. Geological and Natural History Survey of Canada, Report of Progress, 1882–1884, Part GG, 47 p.

CHALMERS, R. 1902. Report on the surface geology shown on the Fredericton and Andover quarter-sheet maps, New Brunswick. Geological Survey of Canada, Annual Report, Vol. XII (1899), Part M, 41 p.

FINAMORE, P.F. 1981. Granular aggregate resources of the Woodstock and Millville map-areas, New Brunswick (N.T.S. 21 J/4 and 21 J/3). New Brunswick Department of Natural Resources, Mineral Development Branch, Open File Report 81-4, 145 p.

FOLK, R.L. 1968. Petrology of sedimentary rocks. Hemphill's, Austin, Texas, 170 p.

FREEWEST RESOURCES CANADA INC. 1999. Freewest drilling identifies broad, multiple gold bearing structures on the Golden Ridge property, New Brunswick. Freewest Resources Canada Inc., Press release, September 29, 1999.

FYFFE, L.R. 1982. Geology, Woodstock. New Brunswick Department of Natural Resources, Mineral Resources Division, Map NR-4.

FYFFE, L.R., and FRICKER, A. 1987. Tectonostratigraphic terrane analysis of New Brunswick. Maritime Sediments and Atlantic Geology, **23**: 113–122.

KETTLES, I.M., and WYATT, P.H. 1986. Reconnaissance geochemical data for till and other surficial sediments, southwestern New Brunswick. Geological Survey of Canada, Open File 1313, 21 p.

LAMOTHE, M. 1990. Till geochemistry over the southern Miramichi Zone and vicinity, New Brunswick. Geological Survey of Canada, Open File 2238, 77 p.

LAMOTHE, M. 1992. Pleistocene stratigraphy and till geochemistry of the Miramichi Zone, New Brunswick. Geological Survey of Canada, Bulletin 433, 58 p.

LEE, H.A. 1962. Surficial geology of Canterbury, Woodstock, Florenceville and Andover map-areas; York, Carleton and Victoria counties, New Brunswick (parts of 21 G/14, 21 J/4, 21 J/5, and 21 J/12). Geological Survey of Canada, Paper 62-12, 8 p.

LYNCH, J. 1990. Provisional elemental values for eight new geochemical lake sediment and stream sediment reference materials LKSD-1, LKSD-2, LKSD-3, LKSD-4, STSD-1, STSD-2, STSD-3 and STST-4. Geostandards Newsletter, **14**: 153–167.

MERLINI, S.A.A. (compiler) 1999. New Brunswick computerized mineral occurrence database (revised 1999). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-12, digital mineral occurrence files.

OSBERG, P.H., HUSSEY, A.M., II, and BOONE, G.M. (editors) 1985. Bedrock geologic map of Maine. Maine Geological Survey, Department of Conservation.

RAMPTON, V.N., GAUTHIER, R.C., THIBAULT, J., and SEAMAN, A.A. 1984. Quaternary geology of New Brunswick. Geological Survey of Canada, Memoir 416, 77 p.

RAMPTON, V.N., and PARADIS, S. 1981. Quaternary geology of Woodstock map area (21 J), New Brunswick. New Brunswick Department of Natural Resources, Mineral Development Branch, Map Report 81-1, 37 p.

ROSE, A.W., HAWKES, H.E., and WEBB, J.S. 1979. Geochemistry in Mineral Exploration, Second Edition. Academic Press, London, 657 p.

SEAMAN, A.A. 1992. Till geochemistry of part of the Forest City (NTS 21 G/12) map area, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 92-6, 88 p.

SEAMAN, A.A. 1993a. Preliminary report – Au, Ag, As, Hg, Sb and base metal values for till samples from the Fosterville (NTS 21 G/13) map area, York and Carleton counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 93-7, 28 p.

SEAMAN, A.A. 1993b. Follow-up till geochemical results for the Forest City (NTS 21 G/12) map area, York County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Open File Report 93-8, 9 p.

SEAMAN, A.A. 1994a. Surficial geology (regolith) mapping and follow-up till and quartz-boulder sampling in the Fosterville (NTS 21 G/13) map area, York and Carleton counties, New Brunswick. *In* Current Research 1993. *Compiled and Edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 12, pp. 166–176.

SEAMAN, A.A. 1994b. Follow-up till geochemistry, Fosterville (NTS 21 G/13) map area, York and Carleton counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File Report 94-8, 26 p.

SEAMAN, A.A. 1995. Till pebble dispersal patterns in the Forest City (NTS 21 G/12) and Fosterville (NTS 21 G/13) map areas, York and Carleton counties, New Brunswick. *In* Current Research 1994. *Compiled and Edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 18, pp. 213–223.

SEAMAN, A.A. 1998. Till geochemistry of the west half of the Millville (NTS 21 J/3) map area, York and Carleton counties, New Brunswick. *In* Current Research 1997. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 98-4, pp. 75–92.

SEAMAN, A.A. 1999a. Till geochemistry of the New Brunswick part of the Forest City (NTS 21 G/12) and Fosterville (NTS 21 G/13) map areas, York and Carleton counties: site and geochemical data. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-7, 67 p.

SEAMAN, A.A. 1999b. Till geochemistry of the Millville (NTS 21 J/3) map area, York and Carleton counties, New Brunswick: site and geochemical data. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-11, 85 p.

SEAMAN, A.A. 2000a. Glacial dispersal in west-central New Brunswick. Atlantic Geoscience Society, Colloquium and Annual General Meeting, Program and Abstracts, p.41.

SEAMAN, A.A. 2000b. Till geochemistry of the New Brunswick part of the Woodstock (NTS 21 J/04) map area, Carleton County: site and geochemical data. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-3, 45 p.

THOMAS, R.D., and GLEESON, C.F. 1988. Metallogeny of the Woodstock area, New Brunswick. Geological Survey of Canada, Open File 1726, 128 p., 3 appendices.

VENUGOPAL, D.V. 1979. Geology of Debec Junction–Gibson Millstream–Temperance Vale–Meductic region, map-areas G-21, H-21, I-21, and H-22 (parts of 21 J/3, 21 J/4, 21 G/13, 21 G/14). New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 79-5, 36 p.

VENUGOPAL, D.V. 1981. Geology of Hartland–Woodstock–Nortondale region, map areas H-19, H-20, I-20 (parts of 21 J/3, 21 J/4, 21 J/5, 21 J/6). New Brunswick Department of Natural Resources, Geological Surveys Branch, Map Report 81-6, 37 p.

A PETROLOGICAL / GEOCHEMICAL STUDY OF A SECTION THROUGH THE PABINEAU SULPHIDE DEPOSIT, BATHURST MINING CAMP, NEW BRUNSWICK (NTS 21 P/05W) ‡

J.A. Walker
New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,
P.O. Box 50, Bathurst, New Brunswick, Canada E2A 3Z1 (e-mail: jim.walker@gnb.ca)

WALKER, J.A. 2000. A petrological / geochemical study of a section through the Pabineau sulphide deposit, Bathurst Mining Camp, New Brunswick (NTS 21 P/05W). *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 73–90.

The Pabineau deposit, located 4 km south-southwest of the Brunswick Mining and Smelting No. 12 mine, is an example of sulphide mineralization occurring in a thrust-repeated slice of the highly productive Brunswick horizon. The stratigraphic succession in the vicinity of the Pabineau deposit comprises, in ascending stratigraphic order, the Patrick Brook, Nepisiguit Falls, and Flat Landing Brook formations.

The section examined in drill hole 121-4 includes approximately 70 m of interbedded shale and wacke assigned to the Patrick Brook Formation. The Patrick Brook Formation is successively overlain by a thin (± 42 m) sequence of interbedded ash tuff and quartz–feldspar-phyric volcaniclastic rocks assigned to the Nepisiguit Falls and by approximately 28 m of felsic ash tuffs that are assigned to the Flat Landing Brook Formation. At the Pabineau deposit, Nepisiguit Falls rocks are distinguished from Flat Landing Brook rocks by lower Zr and Y contents. Furthermore, quartz and feldspar phenocrysts are common in the Nepisiguit Falls and absent in Flat Landing Brook Formation.

Low-grade Pb–Zn mineralization, comprising approximately 136 000 t of semi-massive to massive sulphides grading 2.65% Zn and 0.87% Pb, occurs as fine laminations and as disseminated grains, hosted within the bottom part of the Flat Landing Brook ash tuff sequence. The bulk of the sulphide mineralization occurs stratigraphically below a silica-rich (87 wt. % SiO_2) tuff unit that has trace-element chemistry similar to that of the hanging-wall ash tuffs, i.e., elevated Zr and Y relative to Nepisiguit Falls rocks.

The Flat Landing Brook felsic rocks pass upward into intensely chloritized and deformed mafic volcanic rocks assigned to the Forty Mile Brook tholeiitic basalt member of the Flat Landing Brook Formation.

Le gîte Pabineau, situé à quatre kilomètres au sud-sud-ouest de la mine n° 12 de la Brunswick Mining and Smelting, est un exemple de minéralisation de sulfures présente dans une tranche répétée par chevauchement de l'horizon hautement productif Brunswick. La succession stratigraphique à proximité du gîte Pabineau est constituée, dans un ordre stratigraphique ascendant, des formations de Patrick Brook, de Nepisiguit Falls et de Flat Landing Brook.

---

‡ Contribution to the EXTECH II program (New Brunswick Geological Surveys Branch ordinary budget).

La section examinée dans le trou de forage 121-4 comprend environ 70 m de schiste et de wacke interlités attribués à la Formation de Patrick Brook. Cette formation est successivement recouverte d'une séquence mince (± 42 m) de tuf à base de cendres et de roches volcanoclastiques quartzo-feldspatho-porphyriques attribués à Nepisiguit Falls ainsi que d'environ 28 m de tuf à base de cendres felsiques rattaché à la Formation de Flat Landing Brook. Au gîte Pabineau, on distingue les roches de Nepisiguit Falls des roches de Flat Landing Brook par leurs teneurs inférieures en Zr et en Y. De plus, les phénocristaux de quartz et de feldspath sont répandus dans les roches de Nepisiguit Falls et ils sont absents dans celles de la Formation de Flat Landing Brook.

Une minéralisation à faible teneur en Pb–Zn, renfermant 136 000 t de sulfures semi-massifs à massifs titrant 2,65 % de Zn et 0,87 % de Pb, est présente sous forme de feuillets fins et de grains disséminés à l'intérieur de la partie inférieure de la séquence de tuf de cendres de Flat Landing Brook. La majeure partie de la minéralisation de sulfures se trouve stratigraphiquement au-dessous d'une unité de tuf riche en silice (87 % en masse de SiO_2) ayant une composition chimique en éléments traces analogue à celle des tufs de cendres de l'éponte supérieure, c.-à-d. des teneurs élevées en Zr et en Y comparativement aux roches de Nepisiguit Falls.

Les roches felsiques de Flat Landing Brook se transforment, en allant vers le haut, en roches volcanomafiques intensément chloritisées et déformées, rattachées au membre de basaltes tholéiitiques Forty Mile Brook de la Formation de Flat Landing Brook.

INTRODUCTION

The thrust nappe containing the Pabineau deposit, also known as the Quebec Smelting and Refining (QSR) deposit (New Brunswick Mineral Occurrence Database, URN 0157), is an important sulphide-bearing horizon from an exploration standpoint as it represents a thrust repetition of the highly productive Brunswick horizon (Figure 1). This paper presents the results of petrographic and geochemical work carried out on samples collected from diamond-drill hole 121-4, which intersects the Pabineau sulphide horizon at depth, below the bulk of the mineralization.

LOCATION AND WORK HISTORY

The Pabineau deposit is located approximately 28 km southwest of the city of Bathurst and 4 km south-southwest of the Brunswick Mining and Smelting No. 12 Mine (Figures 1 and 2). Quebec Smelting and Refining Co. discovered the deposit in 1953 as a result of follow-up work on resistivity and magnetic surveys. The first series of holes drilled, DDH QP-1 to QP-6 inclusive, were completed in 1953 (Quebec Smelting and Refining Co. 1953), with an additional 42 drill holes (QP-7 through QP–48) completed in 1957 (Quebec Smelting and Refining Co. 1957). The majority of the holes drilled in these two series tested the Pabineau horizon at fairly shallow (<100 m) depths, with some testing geophysical targets elsewhere on the property.

Brunswick Mining and Smelting drilled four holes (121-1 through 121-4) on the property, testing the horizon at depth beneath known mineralization (Cooper, 1980). Only five complete cores exist for this deposit, namely 121-1 through 121-4 and QP-1, all of which are stored at the Madran core storage facility. In addition to the five complete cores, parts of holes and abbreviated cores from other QP series holes are also available for examination at Madran.

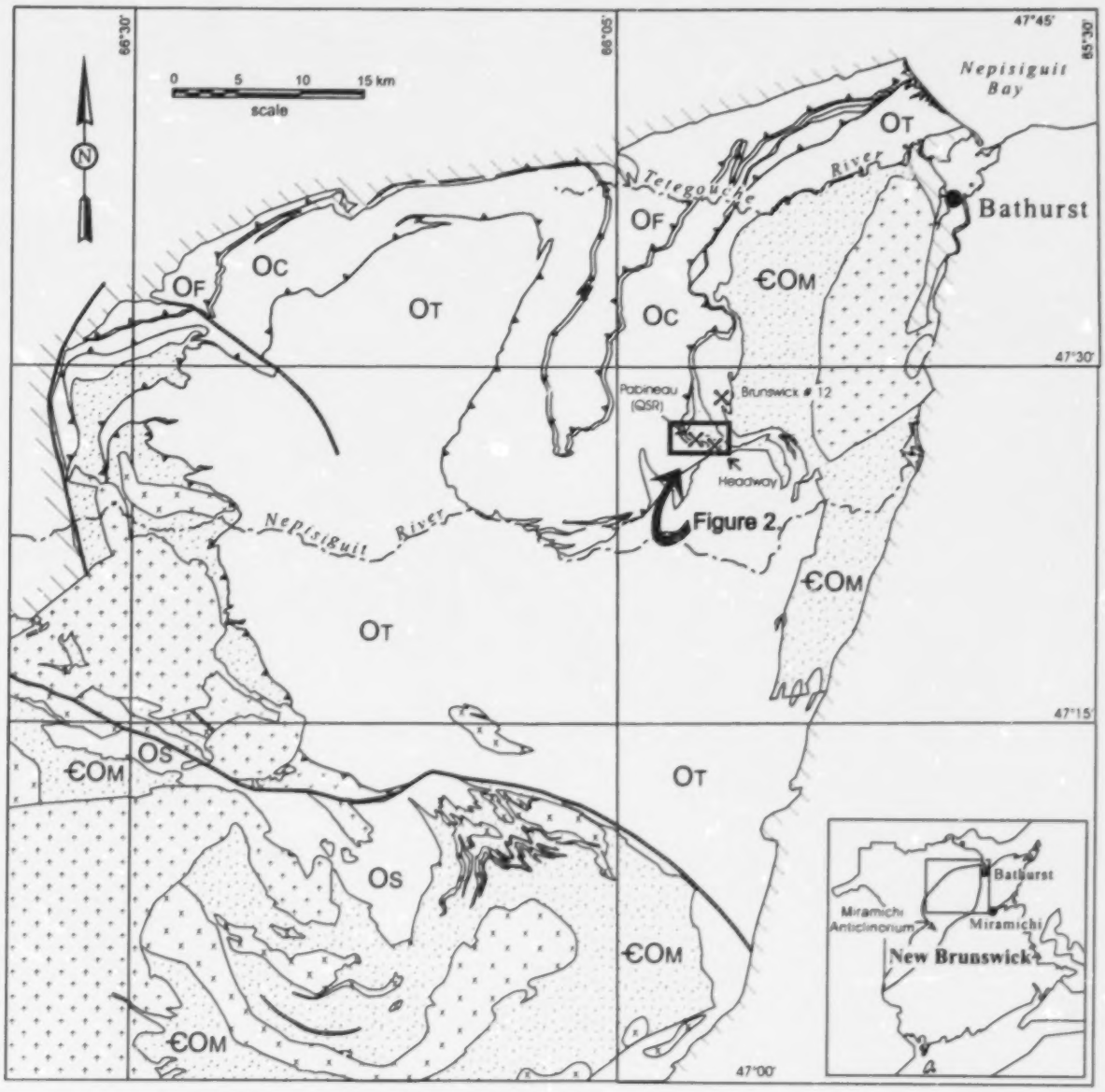
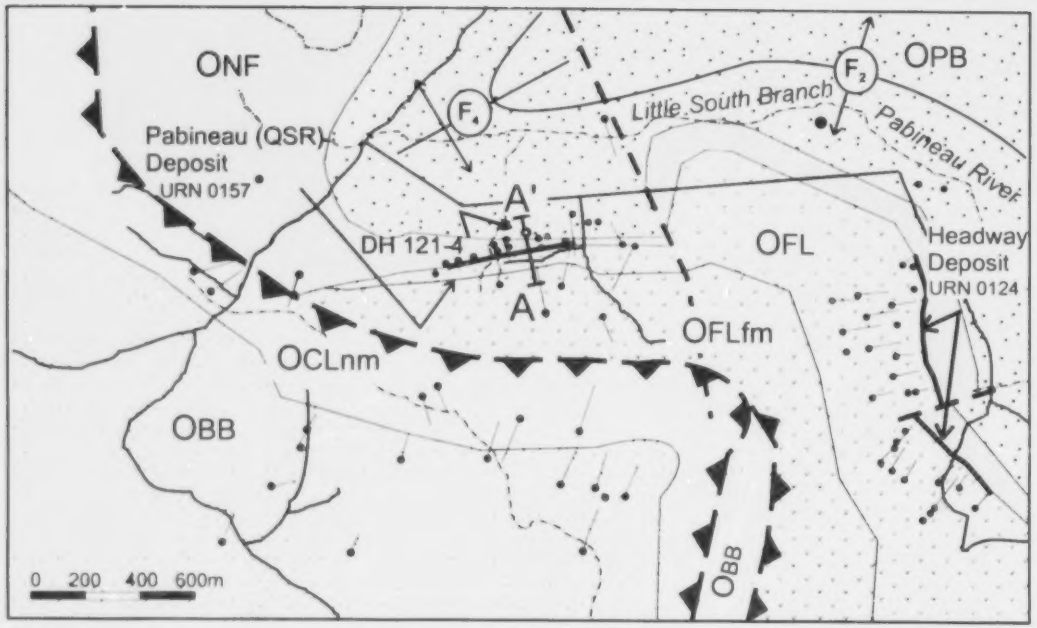


Figure 1. Location map showing the position of the Pabineau deposit (URN 0157) with respect to the Bathurst Mining Camp, Brunswick No. 12 mine (URN 0054), and the Headway deposit (URN 0124). **ЄOM**—Miramichi Group; **OT**—Tetagouche Group; **OC**—California Lake Group; **OF**—Fournier Group; **OS**—Sheephouse Brook Group; [xx] Ordovician granite; [++] Devonian granite. Figure is modified from McCutcheon *et al.* (In preparation). The location of Figure 2 is indicated.

REGIONAL GEOLOGY

The deposit occurs within a polydeformed sequence of fine-grained sedimentary and mafic volcanic rocks of the Ordovician Tetagouche Group. For details on the stratigraphy and structure of the Tetagouche Group, and the Bathurst Mining Camp in general, the reader is referred to papers by van Staal and Fyffe



CALIFORNIA LAKE GROUP

OBB	Boucher Brook Fm. Black to grey shale and minor red shale
OCLnm	Canoe Landing Lake Fm: Basalt flows and related igneous and epiclastic rocks

TETAGOUCHE GROUP

OFL	Flat Landing Brook Fm: Rhyolite flows, domes and related volcanic rocks. OFLfm-Forty Mile Brook tholeiitic basalt
OFLfm	
ONF	Nepisiguit Falls Formation: Quartz-feldspar-phyric lavas and crystal tuff and ash tuff

MIRAMICHI GROUP

OPB	Patrick Brook Formation: Shale and wacke, locally graphitic, locally contains pyrite

thrust fault — road

strike-slip fault — diamond-drill hole

stream — drill hole 121-4

Figure 2. Geology in the vicinity of the Pabineau deposit (modified from van Staal and Rogers 2000). See Figure 1 for location. The distribution of diamond-drill holes in the vicinity of the Pabineau and Headway deposits is also indicated. Note that not all of the drill holes intersecting the sulphide bodies are shown. The line of section A–A' is presented in Figure 3.

(1991), McCutcheon *et al.* (1993), McCutcheon (1997), and van Staal *et al.* (In preparation).

The stratigraphic position of the Pabineau deposit has been interpreted to be the same as that of the Brunswick No. 12 deposit, i.e., at the top of the Nepisiguit Falls Formation. Unlike the No. 12 deposit, which occurs in a para-autochthonous sequence, the Pabineau deposit is situated in a thrust-bound block comprising the upper part of the Miramichi Group (Patrick Brook Formation), and the lower part of the Tetagouche Group (Nepisiguit Falls and Flat Landing Brook formations). This sequence is in thrust contact with mafic volcanic rocks of the Canoe Landing Lake Formation farther to the south (Figures 1 and 2). The Headway deposit (URN 0124) occurs approximately 1400 m along strike to the east of the Pabineau deposit (Figure 2) at a similar stratigraphic level, i.e., near the base of the Flat Landing Brook Formation.

DEPOSIT GEOLOGY

The Patrick Brook Formation is the oldest unit intersected in the footwall, and comprises fine-grained, medium to dark grey sandstone and shale interbedded with medium-grained quartzo-feldspathic wacke. Small (<1 mm) equant crystals of pyrite are disseminated throughout the coarse-grained parts of this unit. Overall, the Patrick Brook Formation appears to become shale dominated toward the south, suggesting a fining-upward (south-facing) sequence.

The Patrick Brook Formation is overlain by a thin (approximately 70 m) felsic sequence. The felsic rocks are divisible into lower and upper parts that are separated by the mineralized horizon. The lower part of the sequence comprises 42 m of interbedded ash and crystal tuff of the Nepisiguit Falls Formation. The most abundant rock type in the lower part of the felsic unit is quartz–feldspar porphyry, which contains quartz and feldspar phenocrysts up to 3.5 mm in long dimension. The matrix of the quartz–feldspar porphyry is dominated by phyllosilicate minerals (white mica and chlorite) and recrystallized quartz. Feldspar is generally well preserved in this sequence, but locally, feldspar pseudomorphs containing masses of quartz and white mica were observed. This texture is indicative of hydrothermal alteration and was described by Lentz and Goodfellow (1993) for Nepisiguit Falls rocks at the Brunswick No. 12 deposit.

The upper 28 m of the felsic sequence is variably mineralized and comprises an interbedded sequence of very fine-grained siliceous ash tuff of the Flat Landing Brook Formation. These rocks locally contain heavily disseminated to semimassive pyrite ± galena, sphalerite and chalcopyrite as fracture fillings. A highly siliceous tuff is coincident with and caps the bulk of the sulphide mineralization in the drill hole sampled and is represented by sample no. 121-4-0697 (see Table 1). Some minor sulphide mineralization persists above the silicified zone. Regional mapping by van Staal and Rogers (2000) places the Nepisiguit Falls–Flat Landing Brook contact somewhere in the middle of the upper part of the felsic sequence. However, as is shown in the section on geochemistry, the hanging wall felsic rocks (including the silicified zone) have trace element values that are dissimilar to those in the footwall; hence the contact should be placed at the mineralized zone. Toward the top of the upper felsic unit the ash tuffs appear to be increasingly deformed.

Mafic rocks of the Forty Mile Brook member (Flat Landing Brook Formation) are interbedded with thin (1–2 m thick) red shale beds. These mafic rocks are probably lava flows, and the red shale represents interflow sedimentary rocks. However, all of these rocks are highly deformed and the mafic volcanic rocks are variably altered to chlorite. Chlorite development is probably a function of deformation rather than hydrothermal alteration related to massive-sulphide generation. Evidence of high strain at the contact

Table 1. Geochemical analyses of samples from diamond-drill hole 121-4 through the Pabineau–QSR horizon.

Sample	121-4-0080	121-4-0346	121-4-526.5	121-4-0562	121-4-0576	121-4-0626	121-4-0697	121-4-0790	121-4-0878	121-4-0908	121-4-1097	121-4-1226
Unit	O_{PB}	O_{PB}	O_{PB}	O_{NF}	O_{NF}	O_{NF}	Exhalite	O_{FL}	O_{FL}	O_{FLfm}	O_{FLfm}	O_{FLfm}
Rock Type	black shale	black shale	black shale	felsic tuff LC	felsic tuff	F-porphyry	siliceous tuff	felsic tuff	Chl. tuff/sed	RMS	mafic tuff	mafic tuff
SiO_2	75.08	48.84	58.75	64.29	45.44	65.99	87.38	77.25	63.34	62.91	39.74	43.39
TiO_2	0.79	1.42	1.07	0.52	1.46	0.37	0.22	0.19	0.47	0.83	1.82	1.76
Al_2O_3	11.11	29.80	21.38	14.47	24.63	15.64	5.64	9.07	18.96	17.68	17.62	16.02
Fe_2O_3	4.97	9.05	9.62	3.74	8.13	3.55	0.99	2.15	3.38	6.15	13.18	9.40
MnO	0.03	0.04	0.07	0.06	0.06	0.04	0.01	0.13	0.06	0.06	0.35	0.47
MgO	1.16	2.27	2.46	2.24	2.29	1.20	0.28	0.99	3.44	1.80	10.97	7.78
CaO	0.36	0.17	0.28	2.09	0.64	1.85	0.86	2.03	0.89	0.88	4.61	7.12
Na_2O	1.45	1.27	0.79	0.80	0.01	0.01	1.11	1.36	0.27	5.28	3.11	3.05
K_2O	1.75	6.31	4.82	4.07	8.33	4.72	1.05	2.57	4.35	2.17	0.75	1.45
P_2O_5	0.14	0.13	0.11	0.13	0.12	0.19	0.08	0.02	0.06	0.11	0.17	0.17
Ba	269	1007	712	608	819	429	178	1204	1942	790	439	3979
Cr	43	140	103	27	111	17	14	10	10	214	446	387
Co	13	35	23	7	18	6	3	1	4	17	53	47
Ga	15.5	43.2	31.5	18.6	37.2	21.6	10.3	14.1	27.6	22.9	22.4	17.1
Ni	13	65	53	15	37	10	2	<1	6	72	172	126
Nb	18	27	23	17	37	15	11	15	23	20	9	9
Pb	21	72	82	40	1032	178	15	12	28	40	16	61
Rb	75	283	200	160	325	196	38	104	134	70	24	31
Sr	72	168	86	161	57	68	66	93	365	200	79	70
Th	10.28	22.98	17.45	15.47	24	13.93	11.24	13.09	25.62	17.59	2.09	1.91
U	<0.0	3.51	1.7	1.19	33.57	4.29	3	<1.00	3.04	<0.0	<0.0	<0.0
V	68	206	146	45	166	32	20	8	34	80	266	271
Y	48	53	39	33	28	31	35	40	80	45	36	29
Zn	81	140	233	49	176	136	23	41	74	62	386	93
Zr	290	200	159	206	365	161	178	243	386	236	109	104
La	41	65	57	39	79	31	34	44	76	38	<0.0	12
Ce	102	127	96	72	138	66	74	55	147	88	<0.0	<0.0
Nd	55	60	46	35	61	42	34	29	82	49	<10	15
TOTAL	96.99	99.62	99.61	92.60	91.44	93.63	97.71	95.97	95.62	98.12	92.58	91.23
Fe/Ti	7.37	7.42	10.45	8.40	6.50	11.18	5.37	13.35	8.49	8.65	8.44	6.24
Al/(Al+Fe+Mn)	0.63	0.71	0.63	0.74	0.69	0.77	0.81	0.75	0.81	0.68	0.50	0.55
Fe+Mg/Na+K	1.65	1.25	1.79	1.00	1.02	0.82	0.51	0.67	1.17	0.94	5.41	3.25
Fe+Mg/Al	0.71	0.49	0.73	0.52	0.54	0.39	0.29	0.44	0.44	0.58	1.70	1.33

Notes: All samples crushed and agate milled at XRAL Laboratories. All analyses carried out by XRF at the University of Ottawa. O_{PB}– Patrick Brook Fm.; O_{NF}–Nepisiguit Falls Fm.; O_{FL}–Flat Landing Brook Fm.; O_{FLfm}–Forty Mile Brook tholeiite.

between these rocks and the underlying felsic sequence suggests a tectonic (thrust) contact that is not indicated on regional mapping (van Staal and Rogers 2000).

South of the sequence intersected in drill hole 121-4, the Forty Mile Brook member is in thrust contact with rocks assigned to the California Lake Group (Figure 2), specifically the Canoe Landing Lake Formation (mafic volcanic rocks) and the overlying Boucher Brook Formation (fine-grained clastic rocks).

STRUCTURE

In the thrust nappe hosting the Pabineau deposit, the Patrick Brook Formation occurs in the core of a tight upright F_2 fold (van Staal and Rogers 2000). North of the deposit, the F_2 axial trace trends north–south, whereas to the east the F_2 axial trace is east–west. The change in orientation of this structure is attributed to F_2 reorientation about a northeast-trending F_4 structure (Lovalls Lake Synform of van Staal 1994).

The mineralized horizon occurs on the south-facing limb of the F_4 structure, strikes east–west, dips near vertically and youngs to the south. Younging direction is determined from large-scale rock distribution rather than small-scale structures. The intense deformation in these rocks obscures or destroys primary sedimentary structures, thereby precluding their use as right-way-up indicators. Mineralization parallels the dominant tectonic fabric, interpreted to be a composite S_1/S_2 fabric defined by preferred orientation of phyllosilicate minerals.

GEOPHYSICS

Resistivity surveys were carried out by Quebec Smelting and Refining Co. in 1953, and follow-up work on areas of anomalous resistivity values led to the discovery of this deposit in 1953.

Gravity surveys on the Pabineau River claim group and encompassing the Pabineau deposit, were carried out by Christopher (1954). Although no details on levelling or on drift corrections are reported, the contour map clearly shows a steady decrease in measured values from 4.4 mgal in the north to values of approximately 2.0 in the south. Values of 3.0 to 3.5 mgal occur over the mineralized zone.

Magnetic highs are not coincident with the Pabineau deposit, suggesting that neither magnetite iron formation nor pyrrhotite are volumetrically significant at this deposit. However, there is a positive magnetic correlation with mafic rocks of the Flat Landing Brook and Canoe Landing Lake formations in the hanging wall (Figure 2).

GEOCHEMISTRY

A total of twelve (12) samples representing all of the major rock types were collected for geochemical analysis. The sampled suite comprises three samples from the lower sedimentary unit, five felsic volcanic samples, one sample of siliceous tuff, two mafic tuff samples, and one sample of red shale associated with the basalt sequence. The positions of these samples with respect to the deposit geology are indicated on the geologic cross-section (Figure 3). All samples were crushed and agate milled at X-Ray Assay Laboratories in Don Mills, Ontario. Geochemical analyses were done by XRF at the University of Ottawa; the results are listed in Table 1.

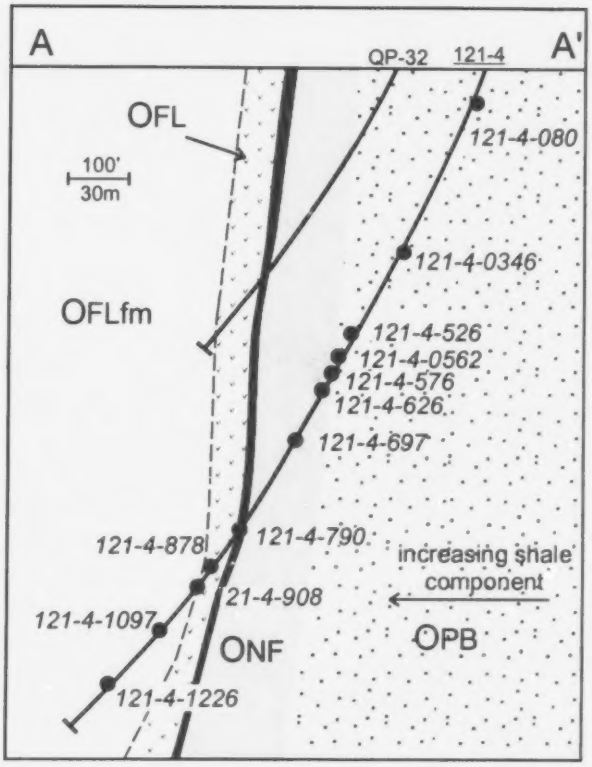


Figure 3. Section through the Pabineau sulphide horizon. See Figure 2 for location and legend. Sample numbers correspond to the tabulated geochemical data presented in Table 1.

Felsic volcanic rocks

On the Nb/Y versus Zr/TiO_2 diagram, most of the quartz–feldspar crystal tuffs and ash tuffs sampled at the Pabineau deposit plot in the rhyodacite/dacite field and one sample plots in the rhyolite field (Figure 4a).

Footwall felsic rocks plot in the middle to lower part of the rhyodacite/dacite field, whereas the hanging-wall felsic rocks plot nearer the upper boundary of this field due to their higher Zr content. This is a significant variation and is generally consistent with the chemistry reported for Nepisiguit Falls and Flat Landing Brook felsic volcanic rocks from elsewhere in the Bathurst Mining Camp (Lentz and Goodfellow 1992; Lentz 1996a). For example, the Flat Landing Brook Formation contains higher high-field-strength elements such as Zr, Nb, Y and Th than Nepisiguit Falls rocks (Lentz and Goodfellow, 1992). This difference is attributed to progressive partial melting of lower crustal material during crustal-extension (Lentz and Goodfellow 1992), giving rise to increased high-field-strength elements in second-stage (later erupted) partial melts. On a Zr/TiO_2 versus SiO_2 diagram (Figure 4b), the wide scatter in the sample set is attributed to highly variable SiO_2 contents of these rocks, making this diagram unacceptable for determination of magmatic affinity. The variability in SiO_2 is due to a combination of hydrothermal alteration and metamorphic (deformation) processes.

On a Y versus Nb tectonic discrimination diagram, the felsic rocks plot near the boundary between the volcanic-arc–syncollisional granite field and the within-plate granite field (Figure 4c). There is a slight separation between hanging-wall and footwall samples that is consistent with the chemical differences reported for Nepisiguit Falls and Flat Landing Brook rocks elsewhere in the Bathurst Mining Camp (Lentz and Goodfellow 1992; Lentz 1996a). One sample of footwall tuff (121-4-0576) has much higher

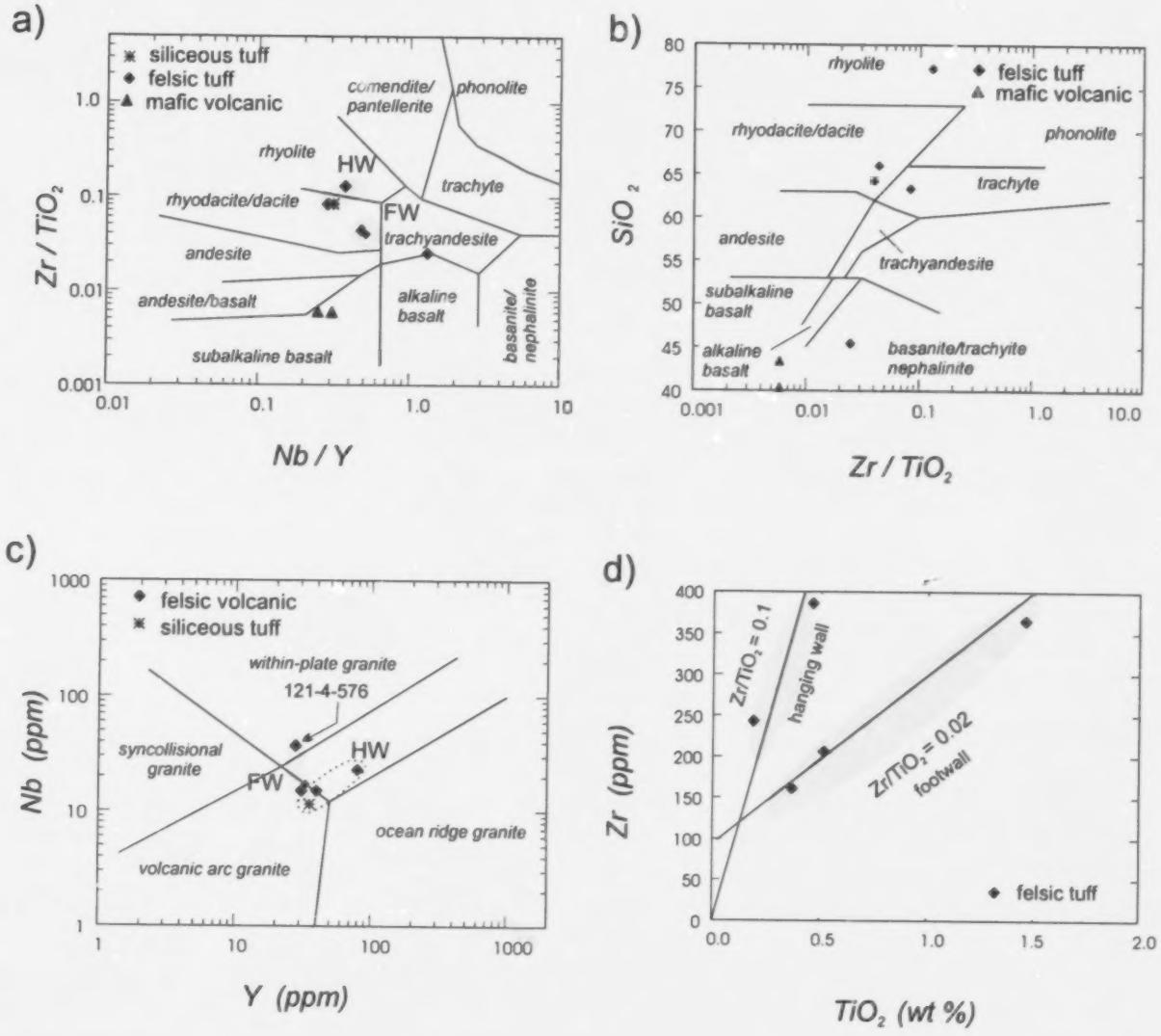


Figure 4. Geochemical discrimination diagrams for samples collected from DDH 121-4 through the Pabineau horizon: (a) Nb/Y versus Zr/TiO_2; and (b) SiO_2 versus Zr/TiO_2 diagrams, modified from Winchester and Floyd (1976); (c) Nb versus Y tectonic discrimination diagram of Pearce *et al.* (1984); (d) Zr versus TiO_2 diagram. **FW**—footwall, **HW**—hanging wall.

Nb (37 ppm) than the other felsic volcanic rocks analyzed. This value is three times higher than the average value (12 ppm) reported for Nepisiguit Falls rocks by Langton and McCutcheon (1993), and is probably a function of mass-loss alteration. Mass-loss in the sample also manifests itself by elevated Zr, U, Pb, Al_2O_3 (24.63 wt. %) and by depleted SiO_2 (45.44 wt. %) relative to the average Nepisiguit Falls composition of Langton and McCutcheon (1993), and to the other felsic rocks sampled (Table 1).

On a Zr versus TiO_2 diagram, the footwall and hanging-wall felsic volcanic rocks define two distinct populations (Figure 4d). The hanging-wall felsic volcanic rocks have Zr/TiO_2 values of approximately 0.1, whereas footwall porphyritic rocks have Zr/TiO_2 values on the order of 0.02. The difference in this

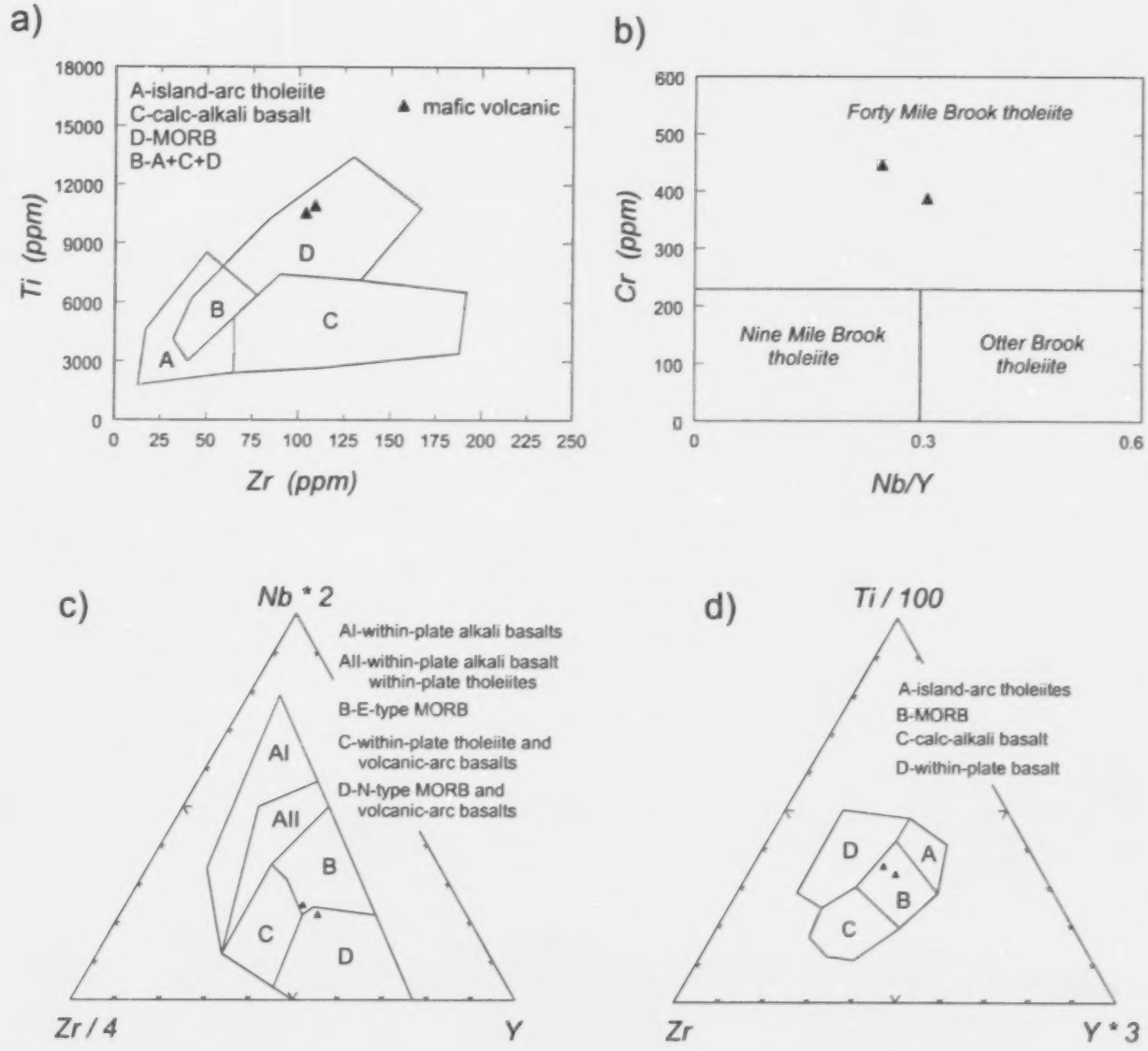


Figure 5. Discrimination diagrams for mafic volcanic rocks from the hanging wall of the Pabineau deposit: (a) Zr versus Ti diagram, after Pearce and Cann (1973); (b) Nb/Y versus Cr diagram, after van Staal *et al.* (1991) and Rogers and van Staal (1996); (c) Zr–Nb–Y diagram, after Meschede (1986); (d) Zr–Ti–Y diagram, after Pearce and Cann (1973).

ratio for the footwall and hanging-wall rocks suggests two distinct magmas, with Zr enrichment in the stratigraphically higher unit attributed to the same progressive partial melting process described above.

Mafic volcanic rocks

Two samples of mafic volcanic rocks collected from diamond drill hole 212-4 plot in the subalkaline basalt field of the Nb/Y versus Zr/TiO_2 diagram (Figure 4a), and in the alkaline basalt field on the SiO_2

versus Zr/TiO_2 diagram (Figure 4b). The same samples plot within the MORB (mid-ocean ridge basalt) field on a Ti versus Zr diagram (Figure 5a).

On the Nb/Y versus Cr discrimination diagram (Figure 5b) of van Staal *et al.* (1991) the mafic volcanic samples plot in the high Cr field, which is consistent with values from the Forty Mile Brook tholeiite reported by van Staal and Rogers (2000). On the Zr–Nb–Y and Zr–Ti–Y ternary discrimination diagrams (Figures 5c and 5d) the mafic samples plot in the MORB and ocean floor basalt fields, respectively.

The mafic rocks have undergone intense deformation as evidenced by the presence of a strong penetrative fabric. Locally, large "bull-quartz" veins occur within the mafic sequence; such veins commonly accompany intense deformation and are probably related to D_1 thrusting. In thin section, these rocks are almost completely altered to chlorite, which is evident from elevated MgO (10.97 wt. %) and Fe_2O_3 (13.18 wt. %) values relative to the average Forty Mile Brook tholeiite values (MgO = 7.64 wt. %) and Fe_2O_3 = 10 wt. %) presented in van Staal *et al.* (1991). The chlorite development is probably related to deformation rather than hydrothermal alteration.

Sedimentary rocks

Three samples of fine-grained shale from the Patrick Brook Formation and one sample of red shale from the Forty Mile Brook member were analyzed. A plot of Fe/Ti versus Al/(Al+Fe+Mn) as modified from Bostrom (1973) shows that these sedimentary rocks have very little in the way of hydrothermal input. This is not surprising as stratiform volcanogenic-massive-sulphide-style mineralization has not been reported in Patrick Brook or Forty Mile Brook member rocks elsewhere in the Bathurst Mining Camp. However, cross cutting hydrothermal alteration has been reported in Miramichi Group rocks elsewhere, i.e., the Fab zone (Lentz and Goodfellow 1994).

Siliceous tuff / Sulphide horizon

A siliceous tuff (exhalite field term) horizon occurs near the top of the mineralized zone. This unit contains >87% SiO_2, mostly as recrystallized quartz, as well as white mica and minor disseminated to laminated sulphides. Initial observations suggest that this unit is a silica-rich exhalitive unit that caps the quartz–feldspar-phyric rocks of the Nepisiguit Falls Formation. Geochemically, there are problems with this interpretation because the one sample that was analyzed plots well to the right on the Fe/Ti versus Al/(Al+Fe+Mn) hydrothermal component index, indicating that the rock does not have a strong hydrothermal component. However, this discrimination diagram was designed for sedimentary rocks and may not be particularly applicable to rocks that contain a significant volume of juvenile felsic volcanic material. An additional problem with the assignment of this unit to the Nepisiguit Falls Formation is evident in the light of Nb/Y versus Zr/TiO_2 variation diagram (Figure 4a). The siliceous unit has Nb/Y and Zr/TiO_2 values that are quite similar to the hanging-wall felsic tuffs (Flat Landing Brook Formation) rather than the Nepisiguit Falls Formation. From the above observations, it seems likely that this siliceous unit is probably a hanging-wall tuff that has been subjected to significant silica addition rather than a true hydrothermally generated siliceous exhalite.

Mineralization in drill hole 121-4 comprises finely laminated to disseminated sulphides hosted in an ash tuff. The mineralized horizon is reported (McCutcheon *et al.* in preparation) to have a maximum thickness of 4.5 m, a strike length of 122 m and a down-dip extent of 91 m. The total geological resource has been estimated at 136 000 t of semi-massive to massive sulphides grading 2.65% Zn and 0.87% Pb (McCutcheon *et al.* In preparation). Work conducted during this project confirms observations made by Cooper (1980) concerning the apparently remobilized nature of the sulphides (grain-size slightly coarser than other Bathurst Mining Camp deposits).

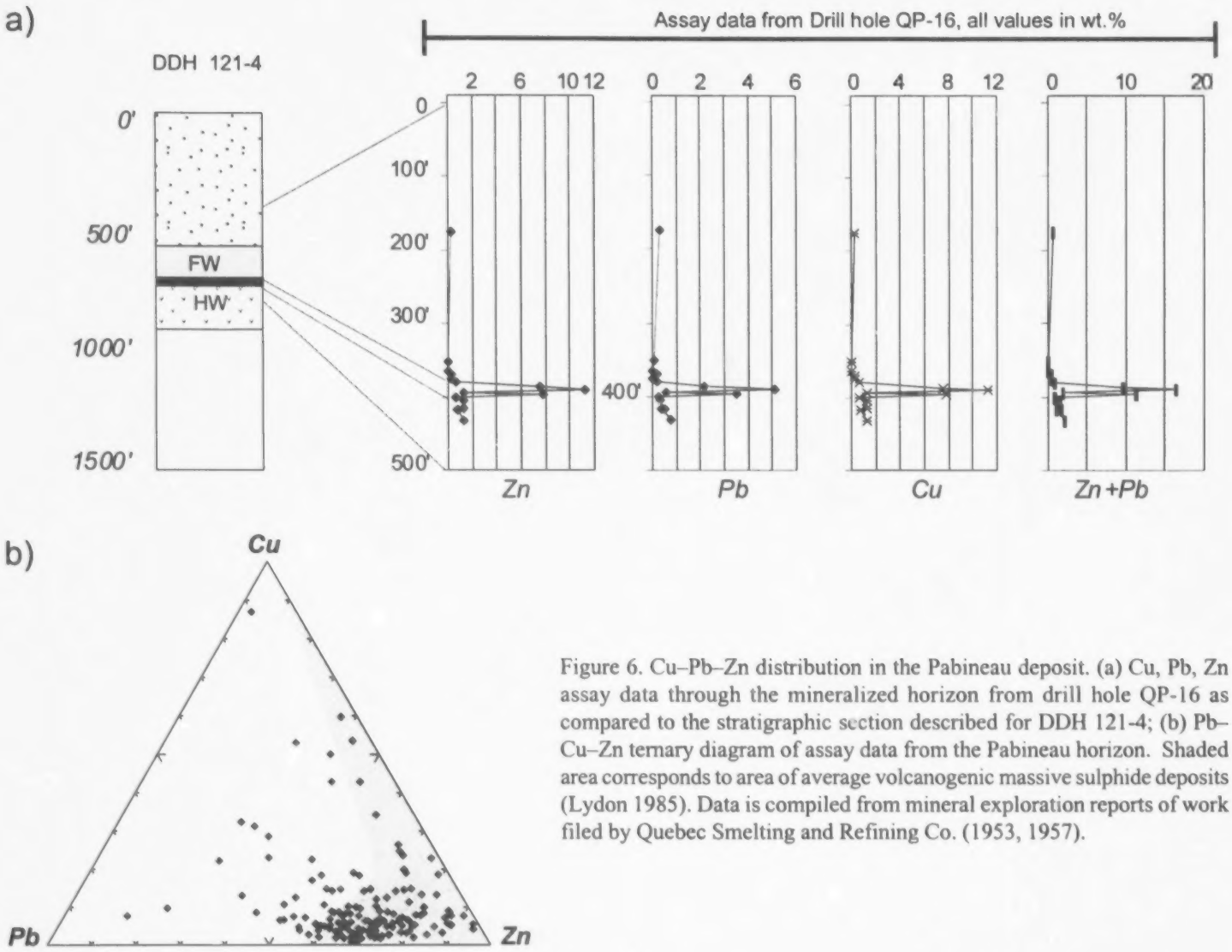


Figure 6. Cu–Pb–Zn distribution in the Pabineau deposit. (a) Cu, Pb, Zn assay data through the mineralized horizon from drill hole QP-16 as compared to the stratigraphic section described for DDH 121-4; (b) Pb–Cu–Zn ternary diagram of assay data from the Pabineau horizon. Shaded area corresponds to area of average volcanogenic massive sulphide deposits (Lydon 1985). Data is compiled from mineral exploration reports of work filed by Quebec Smelting and Refining Co. (1953, 1957).

Profiled assay data from DDH QP-16 relative to deposit stratigraphy (DDH 121-4) illustrates that Zn, Pb, Cu and Zn+Pb values are lowest immediately below the sulphide zone whereas, immediately below the siliceous tuff horizon, they reach maximum values (Figure 6a). The immediate hanging-wall felsic tuffs are enriched in Cu, Pb and Zn relative to the immediate footwall. The base-metal-depleted footwall rocks could reflect efficient metal leaching by hydrothermal fluids below the sea-water-sediment interface. Conversely, the slightly elevated Cu, Pb, Zn values in the hanging wall may indicate waning hydrothermal venting coincident with deposition of younger felsic tuffs.

More than 360 assays of drill core obtained from this property are filed for assessment, most of which report only Pb and Zn ± Ag values. Those assays reporting values for Pb, Zn and Cu are plotted on a Pb–Cu–Zn ternary diagram (Figure 6b). It is clear that the Pabineau mineralization is Zn-dominant and contains very little Cu. These base-metal ratios are typical of the Bathurst Mining Camp deposits specifically, and of felsic volcanic-related volcanogenic massive sulphide deposits world-wide (Franklin *et al.* 1981). Most of the logs inspected have assays that indicate increasing Pb+Zn toward the top of the sulphide-bearing horizon. However, the absence of any core assays with consistently elevated Cu values precludes the identification of a Cu-rich stringer zone from the assessment data.

Metal zonation is not well developed along the Pabineau horizon. Assays from the QSR and Brunswick Mining and Smelting drill holes show no well-defined metal zonation from a Cu-rich base and stringer zone to a Pb–Zn-rich top (Figure 6a). Assays from hole 212-4 do show a positive correlation between Pb content and Ag grades, which is explained by the incorporation of Ag into the galena structure.

Unlike deposits occurring at the Brunswick horizon, the Pabineau deposit is not capped by or laterally equivalent to Algoma-type iron formation. A similar observation has been made at the Key Anacon deposit (Irrinki 1992), where iron formation is absent and mafic volcanic and related sedimentary rocks directly overlie mineralization at the top of the Nepisiguit Falls Formation.

Alteration

The degree of hydrothermal input into the felsic units is relatively small, as shown by Figure 7a. A plot of Fe/Ti versus Al/(Al+Fe+Mn) shows that the felsic tuffs from both the Nepisiguit Falls and Flat Landing Brook formations and the shale from the Patrick Brook Formation all have only a minor hydrothermal component. Instead, these samples compare favorably with average values for alkalic basalt, felsic volcanic (Nepisiguit Falls and Flat Landing Brook formations) and Miramichi sedimentary rock samples (Lentz *et al.* 1995).

The absence of hydrothermal input in the Patrick Brook Formation is not surprising since the Miramichi Group generally predates the rifting that generated the volcanogenic massive sulphide deposits of the Bathurst Mining Camp (van Staal and Fyffe 1991; McCutcheon *et al.* 1993). However, a significant hydrothermal component should be detectable in the immediate footwall and hanging wall of a volcanogenic massive sulphide deposit, provided the deposit was not immediately buried by detrital and/or volcanic material following sulphide deposition. The apparent increase in hydrothermal input in the mafic volcanic rocks is a function of chloritization associated with deformation (Figure 7a).

On an (Fe+Mg)/(Na+K) versus (Fe+Mg)/Al alteration index diagram (Figure 7b), the felsic volcanic rocks vary only slightly from values for average unaltered Nepisiguit Falls and Flat Landing Brook formations (Langton and McCutcheon 1993). On the same diagram (Figure 7b), two of the shale samples are slightly more altered.

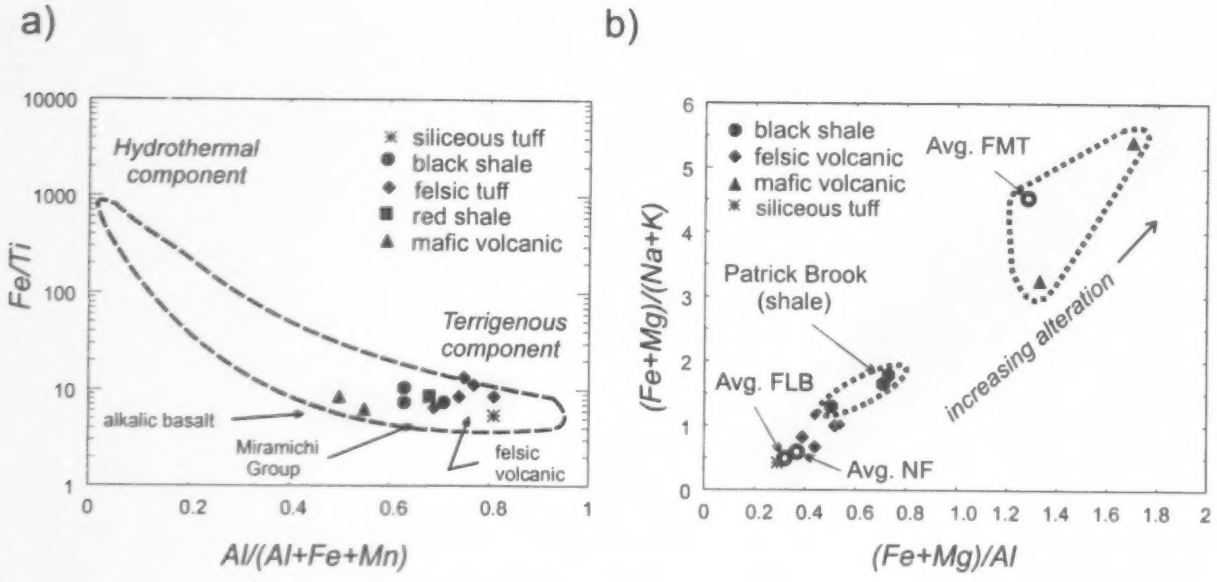


Figure 7. Alteration chemistry discrimination diagrams for samples collected from DDH 121-4 through the Pabineau deposit. (a) Al/(Al+Fe+Mn) versus Fe/Ti, modified from Bostrom (1973). Fields for alkalic basalt, Miramichi Group, and felsic volcanic are from Lentz *et al.* (1995); (b) (Fe+Mg)/Al versus (Fe+Mg)/(Na+K) diagram, modified from Lentz (1996a). Average Nepisiguit Falls (**NF**) and Flat Landing Brook (**FLB**) values are from Langton and McCutcheon (1993); average Forty Mile Brook tholeiite values are from van Staal *et al.* (1991).

Figure 8 shows several alteration indices profiled in relation to rock units in DDH 212-4. Some of these profiles reflect protolith composition, i.e., the (Fe+Mg)/(K+Na) values for hanging-wall mafic rocks are several times higher than those from the felsic sequence. These values are typical for alkalic basalt in the Bathurst Mining Camp and reflect the high Mg and Fe content in basalt relative to felsic rocks, coupled with deformation-induced chloritization of these rocks. The (Fe+Mg)/Al ratio, which is an indicator of the degree of chloritization, generally increases from footwall sedimentary rocks through the felsic volcanic sequence to just below the contact with the mafic sequence (Figure 8). Two exceptions to this trend occur, namely: (1) visibly unaltered quartz–feldspar porphyry at the base of the Nepisiguit Falls Formation has a low value, and (2) the silica-rich unit capping the sulphide zone also has a low value.

The K/Na ratio is a good indicator of footwall hydrothermal alteration in the drill hole sampled, with very high values coincident with the most intense hydrothermal alteration (Figure 8). The elevated K values are attributable to sericite development, whereas Na loss is assumed to be a function of leaching by acidic hydrothermal solutions. The Mn/Fe ratio is somewhat useful as it shows a slight gradual increase approaching mineralization from the footwall and gives the highest values at and slightly above the mineralized zone. This indicates prolonged hydrothermal activity following the bulk of the sulphide deposition. Other potentially useful indices are the Fe/Ti, Pb+Zn and Mg/Fe (Figure 8).

DISCUSSION

Trace-element chemistry at the Pabineau deposit, discussed above, suggests that the mineralization occurs at the base of the Flat Landing Brook Formation, just above the Brunswick horizon (top of the Nepisiguit

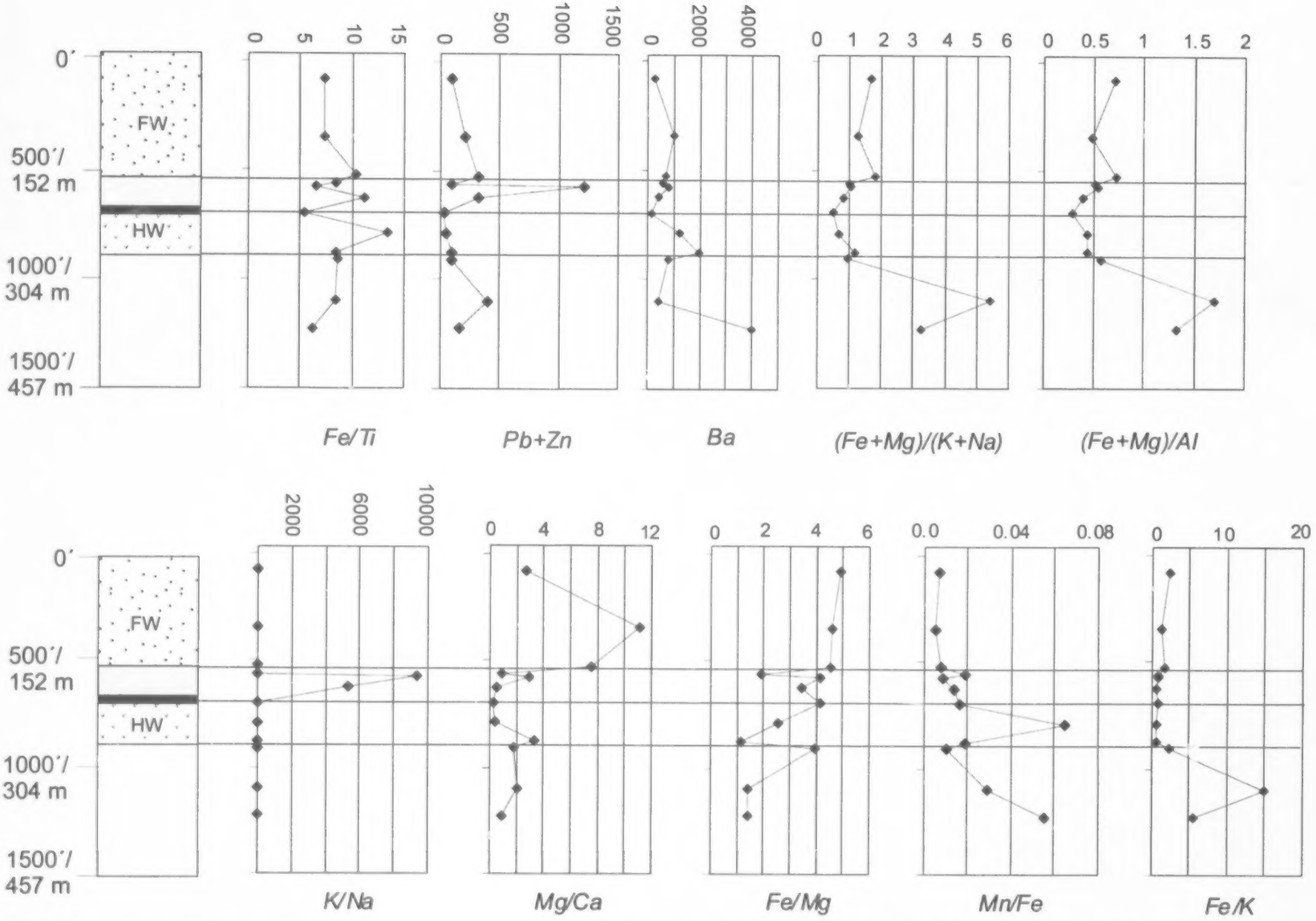


Figure 8. Alteration indices as profiles along diamond drill hole 121-4. Rock type symbolization is the same as in Figures 3 and 4. **FW**—footwall; **HW**—hanging wall; ▬ siliceous tuff horizon.

Falls Formation). Both the Headway deposit and the Grandroy occurrence (Lentz 1996b) are examples of mineralization at this stratigraphic level, i.e., near the base of the Flat Landing Brook Formation overlying a very thin unit of epiclastic Nepisiguit Falls rocks.

The absence of a well-developed sedimentary horizon at the contact between the Nepisiguit Falls Formation and the overlying Flat Landing Brook Formation, in the vicinity of the Pabineau deposit, may preclude the possibility of a large-tonnage Brunswick-type deposit. However, the presence of known mineralization along strike to the southeast (e.g., Headway and Grandroy), coupled with a very low outcrop density, makes this a prospective horizon for exploration. In particular, the fold hinge between the Pabineau and Headway deposits has been tested at depth by very few drill holes (Figure 2). The low Pb+Zn values, very low Cu content and apparent absence of metal zoning at this deposit suggest that the as-yet unrecognized feeder zone may be quite distant, which also enhances the potential for further discoveries along strike or down-dip. The interpretation of this deposit as vent-distal, based on metal zoning, is supported by the relatively weak hydrothermal signature in the footwall and hanging-wall felsic volcanic rocks.

To the west and north, regional mapping (van Staal and Rogers 2000) shows that Nepisiguit Falls rocks are cut out by a thrust, thereby limiting the possibility of a surface discovery. However, the potential for mineralization at depth along this horizon remains.

CONCLUSIONS

The Pabineau deposit occurs at the contact between quartz–feldspar porphyritic rocks of the Nepisiguit Falls Formation and overlying felsic ash tuffs of the Flat Landing Brook Formation. The stratigraphy in the vicinity of the Pabineau deposit is unique in that the felsic sequence is extremely thin (<60 m) and comprises roughly 42 m of Nepisiguit Falls and 28 m of Flat Landing Brook rocks. The thin felsic pile in this area may be the result of basin topographic control but more likely is an artifact of deformation. Intense chloritic alteration, and well-developed deformation textures (recrystallization, well-developed foliation) in the hanging-wall mafic rocks suggest the possibility of a thrust / synvolcanic fault between the hanging-wall felsic tuffs and mafic volcanic rocks.

Stratigraphy, together with a somewhat skewed $\sum$Pb+Zn distribution, suggests that the deposit youngs to the south. The absence of any concentration of significant Cu assays and the moderate to high strain in these rocks precludes the easy identification of a stringer–stockwork zone.

ACKNOWLEDGEMENTS

This work was conducted as part of the EXTECH-II project in the Bathurst Mining Camp and has benefited from discussions with and critical reviews by S.R. McCutcheon and R.A. Wilson.

REFERENCES

Bostrom, K. 1973. The origin and fate of ferromanganoan active ridge sediments. Stockholm Contributions to Geology, **27:** 147–242.

Christopher, Y. 1954. Report of gravity survey on the Pabineau River Group. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 472324.

COOPER, P.C. 1980. Report of work on Projects 118 and 121, Lovall's Lake, Bathurst Parish, Gloucester Co. N.B. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 472531.

FRANKLIN, J.M., LYDON, J.W., and SANGSTER, D.F. 1981. Volcanic associated massive sulfide deposits: Economic Geology, 75th Anniversary Volume: 485–627.

IRRINKI, R.R. 1992. Key Anacon sulfide deposit, Gloucester County, New Brunswick. Exploration and Mining Geology, **1**: 121–129.

LANGTON, J.P., and MCCUTCHEON, S.R. 1993. Brunswick Project, NTS 21 P/5 West, 21 P/4 West, Gloucester County, New Brunswick. *In* Current Research. Compiled and Edited by S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Information Circular 93-1, pp. 31–51.

LENTZ, D.R. 1996a. Trace-element systematics of felsic volcanic rocks associated with massive-sulphide deposits in the Bathurst Mining Camp: Petrogenetic, tectonic and chemostratigraphic implications for VMS exploration. *In* Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration. *Edited by* D.A. Wyman. Geological Association of Canada, Short Course Notes, **12**: 359–402.

LENTZ, D.R. 1996b. Geology and structure in the Grandroy area south of the Brunswick No. 12 massive-sulphide deposit, New Brunswick. *In* Current Research 1996-D. Geological Survey of Canada, pp. 71–80.

LENTZ, D., and GOODFELLOW, W. 1992. Re-evaluation of the petrochemistry of the felsic volcanic and volcaniclastic rocks near the Brunswick No. 6 and 12 massive sulphide deposits, Bathurst Mining Camp, New Brunswick. *In* Current Research, Part E. Geological Survey of Canada, Paper 92-1E, pp. 343–350.

LENTZ, D., and GOODFELLOW, W. 1993. Petrology and mass balance constraints on the origin of the quartz augen schist associated with the Brunswick massive sulfide deposits, Bathurst, New Brunswick. Canadian Mineralogist, **31**: 877–903.

LENTZ, D., and GOODFELLOW, W. 1994. Petrology and geochemistry of altered volcanic and sedimentary rocks associated with the FAB stringer sulphide zone, Bathurst, New Brunswick. *In* Current Research 1994-D. Geological Survey of Canada, pp. 123–133.

LENTZ, D.R., MCCUTCHEON, S.R., and WALKER, J.A. 1995. Preliminary geochemical interpretation of metalliferous sedimentary rocks in the Miramichi Anticlinorium, New Brunswick. *In* Current Research 1994. *Compiled and edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 18, pp. 91–111.

LYDON, J.W. 1985. Volcanogenic massive sulphide deposits, Part 1: A descriptive model. *In* Geoscience Canada, Reprint Series 3. *Edited by* R.G. Roberts and P.A. Sheahan, pp. 145–152.

MCCUTCHEON, S.R., LANGTON, J.P., VAN STAAL, C.R., and LENTZ, D.R. 1993. Stratigraphy, tectonic setting and massive-sulphide deposits of the Bathurst Mining Camp, northern New Brunswick. *In* Guidebook to the Metallogeny of the Bathurst Camp, Field Trip # 4. *Edited by* S.R. McCutcheon.

MCCUTCHEON, S.R. 1997. Geology of the massive sulphides of the Bathurst Camp, New Brunswick. Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Ottawa '97, Field Trip B7, Guidebook, p. 85.

MCCUTCHEON, S.R., LUFF, W.M., and BOYLE, R.W. In preparation. The Bathurst Mining Camp, New Brunswick, Canada: History of discovery and evolution of geological models. *In* Massive Sulfide Deposits of the Bathurst Mining Camp, New Brunswick, and Northern Maine. *Edited by* W.D. Goodfellow, S.R. McCutcheon, and J.M. Peter. Economic Geology Monograph.

MESCHEDE, M. 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb–Zr–Y diagram. Chemical Geology, **56**: 207–218.

PEARCE, J.A., and CANN, J.R. 1973. Tectonic setting of basic volcanic rocks determined using trace element analysis. Earth and Planetary Science Letters, **19**: 290–300.

PEARCE, J.A., HARRIS, N.B.W., and TINDLE, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology, **25**: 956–983.

QUEBEC SMELTING and REFINING Co. 1953. Report of drilling and geophysical surveys on the Pabineau River Group. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 472323.

QUEBEC SMELTING and REFINING Co. 1957. Report of drilling on the Pabineau River Group. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471252.

ROGERS, N. and VAN STAAL C. 1996. The distribution and features of the Spruce Lake Formation, Tetagouche Group, New Brunswick. *In* Current Research 1996-D. Geological Survey of Canada, pp. 61–91.

VAN STAAL C.R. 1994. The geology of Brunswick Mines, New Brunswick. Geological Survey of Canada, Map 1836A (Scale 1:20 000).

VAN STAAL, C.R., and FYFFE, L.R. 1991. Dunnage and Gander zones, New Brunswick: Canadian Appalachian Region. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Geoscience Report 91-2, 39 p.

VAN STAAL, C.R., and ROGERS, N. 2000. Geology of the northern part of the Bathurst Mining Camp (part of NTS 21 P/5), New Brunswick. Geological Survey of Canada, Open File 3839, sheet 8 of 8 (scale: 1:20 000).

VAN STAAL, C.R., WINCHESTER, J.A., and BEDARD, J.H. 1991. Geochemical variations in middle Ordovician volcanic rocks of the northern Miramichi Highlands and their tectonic significance. Canadian Journal of Earth Sciences, **28**: 1031–1049.

VAN STAAL, C., WILSON, R., FYFFE, L., LANGTON, J., MCCUTCHEON, S., MCNICHOLL, V., RAVENHURST, C., and ROGERS, N. In preparation. Geology and tectonic history of the Bathurst Mining Camp – A synthesis. *In* Massive Sulfide Deposits of the Bathurst Mining Camp, New Brunswick, and Northern Maine. *Edited by* W.D. Goodfellow, S.R. McCutcheon, and J.M. Peter. Economic Geology Monograph.

WINCHESTER, J.A., and FLOYD, P.A. 1976. Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology, **20**: 325–343.

GEOLOGY OF THE POPELOGAN LAKE–LOST PINE LAKE AREA (NTS 21 O/15a AND b), RESTIGOUCHE COUNTY, NEW BRUNSWICK †††

R.A. Wilson

New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,
P.O. Box 50, Bathurst, New Brunswick, CANADA E2A 3Z1 (e-mail: reg.wilson@gnb.ca)

WILSON, R.A. 2000. Geology of the Popelogan Lake–Lost Pine Lake area (NTS 21 O/15a and b), Restigouche County, New Brunswick. *In* Current Research 1999. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-4, pp. 91–136.

The Popelogan Lake–Lost Pine Lake area is underlain by Middle to Upper Ordovician rocks of the Balmoral Group, and disconformably overlying Lower Silurian rocks of the Matapédia Group and the Upsalquitch Formation (Chaleurs Group). The Balmoral Group comprises volcanic arc-related, amygdaloidal, basaltic to andesitic flows and picritic lapilli tuffs of the Goulette Brook Formation, and overlying dark green to black, locally graphitic and graptolite-bearing shales and cherts of the Popelogan Formation. The Matapédia Group consists of Lower Silurian calcareous turbidites that, based on age and lithological correlations with the Gaspé section, are assigned to the L'Irlande Member of the White Head Formation. Lithotypes are typical of sediments deposited on a submarine slope, and include a thin-bedded calcilutite–calcareous shale facies, and a massive calcilutite facies characterized by thin laminae of fine-grained calcarenite; shale and calcareous siltstone occur in minor amounts.

The Upsalquitch Formation gradationally overlies the White Head Formation, and is subdivided into three informal members based on differences in lithology and sedimentary structures. The Arsenault Brook member is present only locally, and consists of thin-bedded calcareous siltstone intercalated with thicker beds (up to 50 cm) of micaceous, parallel-laminated calcarenite or calcareous sandstone interpreted as turbidite deposits. The White Meadows member is composed mainly of thin-bedded, commonly bioturbated, slightly micaceous calcareous siltstone and coarse-grained calcilutite, with minor shale and local thin, cross-laminated beds or laminae of calcarenite. The Narrows Brook member comprises thin-bedded, micaceous, locally bioturbated, fine-grained arkosic to feldspathic sandstone or siltstone. The White Head and Upsalquitch formations define a shallowing-upward sequence that reflects regional uplift in the Early Silurian; chemical signatures indicate a significant continental volcanic-arc influence in the terrestrial component of these rocks, with increasing input from a continental source over time. All rocks in the area are relatively weakly deformed, including those of the Balmoral Group in the core of the Popelogan Anticline, where no penetrative axial-planar cleavage is present. East of the axis of the Popelogan Anticline, which is the major structural feature in the area, Upsalquitch strata generally have shallow dips and lack cleavage; the rocks are thrown into gentle, northeast-plunging folds such as the Narrows Brook Syncline. West of the axis of the Popelogan Anticline, bedding in the White Head and Upsalquitch formations is more steeply dipping; folds are open to close, with moderately well developed axial-planar cleavage, and plunge gently to the southwest.

Intrusive rocks include felsic to intermediate plutonic rocks of the Middle Devonian Red Brook Granodiorite, and felsic to mafic dykes and sills that occur throughout the survey area. The Red Brook Granodiorite is a composite, multi-phase pluton with associated dykes, sills and apophyses that are genetically linked to the Popelogan copper skarn deposit near the western margin of the intrusion. The Red Brook Granodiorite is typical of calc-alkalic, I-type intrusions commonly

††† Contribution to the Appalachian Foreland and Platform NATMAP project.

associated with convergent plate margins. Two populations of dykes and sills are present: microgranites with very felsic compositions and trace-element signatures similar to A-type, within-plate granites, and intermediate feldspar porphyries that are chemically identical to the Red Brook Granodiorite. The feldspar porphyries are interpreted as being co-magmatic with the Red Brook Granodiorite (i.e., Middle Devonian), whereas the microgranites chemically resemble Late Silurian to earliest Devonian intrusions in northern New Brunswick and, therefore, may be considerably older than the feldspar porphyries. Low-grade copper mineralization at the Popelogan deposit is hosted by a broad zone of contact metasomatic alteration (skarn, hornfels and porcellanite) in the White Head and Upsalquitch formations, near the western margin of the Red Brook Granodiorite. The resource has been estimated at 3 000 000 t of 0.3% Cu. Porcellanite alteration like that at the Popelogan deposit has also been observed in the Upsalquitch Formation in the eastern part of the survey area, where it constitutes at least 5% of a 100 m stratigraphic section along Narrows Brook. Several base-metal occurrences are hosted by mafic volcanic rocks of the Goulette Brook Formation, including a 7 m interval that assayed 1.14% Zn and 0.12% Cu in a hole recently drilled to the southwest of the Popelogan deposit.

Le secteur des lacs Popelogan et Lost Pine repose sur des roches de l'Ordovicien moyen à supérieur du groupe de Balmoral et il recouvre de façon discordante des roches du Silurien inférieur du groupe de Matapédia et de la Formation d'Upsalquitch (groupe de Chaleurs). Le groupe de Balmoral est constitué de coulées amygdaloïdes, basaltiques à andésitiques apparentées à un arc insulaire et de conglomérat volcanique à lapilli de la Formation de Goulette Brook, ainsi que de schistes et de cherts sus-jacents passant du vert foncé au noir, localement graphitiques et renfermant des graptoliltes, de la Formation de Popelogan. Le groupe de Matapédia est constitué de turbidites calcaires du Silurien inférieur qui, d'après leur âge et des corrélations lithologiques avec la section de Gaspé, sont attribuées au membre L'Irlande de la Formation de White Head. Les lithotypes sont caractéristiques des sédiments déposés sur une pente sous-marines et ils comprennent un faciès de schistes à base de calcilutite-calcaire finement stratifié ainsi qu'un faciès de calcilutite massif caractérisé par de minces lames de calcarénite à grain fin; du microgrès schisteux et calcareux est présent en quantités restreintes.

La Formation d'Upsalquitch recouvre de façon progressive la Formation de White Head; on la subdivise en trois membres naturels en fonction des différences relevées dans les structures lithologiques et sédimentaires. Le membre Arsenault Brook n'est présent que localement; il est constitué de microgrès calcareux finement stratifié parmi lequel sont intercalées des strates plus épaisses (ayant jusqu'à 50 cm) de grès calcaire ou de calcarénite à stratification parallèle micacés, interprétées comme des dépôts de turbidite. Le membre White Meadows se compose principalement de microgrès calcareux légèrement micacé communément bioturbé et finement stratifié avec de petites quantités de schiste et de minces strates ou lames de calcarénite à stratification croisée par endroits. Le membre Narrows Brook est constitué de grès ou de microgrès arkosique à feldspathique à grain fin localement bioturbé, micacé et finement stratifié. Les formations de White Head et d'Upsalquitch définissent une séquence moins profonde vers le haut, qui témoigne d'un soulèvement régional au cours du Silurien précoce; les signatures chimiques révèlent une influence déterminante d'un arc insulaire continental dans la composante terrestre de ces roches, avec apport croissant d'une source continentale au fil du temps. Toutes les roches du secteur sont relativement peu déformées, y compris celles du groupe de Balmoral dans le cœur du pli anticlinal de Popelogan, où est présent un clivage ardoisier axial pénétrant. À l'est de l'axe du pli anticlinal de Popelogan, qui constitue la principale particularité structurale du secteur, les strates d'Upsalquitch s'inclinent généralement peu profondément et sont dépourvues de schistosité; les roches ont été repoussées dans des plis plongeant doucement vers le nord-est, comme le pli synclinal de Narrows Brook. À l'ouest de l'axe du pli anticlinal de Popelogan, le litage des formations de White Head et

d'Upsalquitch s'incline plus abruptement; les plis varient des plis ouverts à fermés, avec un clivage ardoisier axial moyennement développé, et ils plongent doucement vers le sud-ouest.

Les roches intrusives comprennent des roches plutoniques feldspathiques à intermédiaires provenant de la granodiorite du Dévonien moyen de Red Brook de même que des dykes et des filons-couches felsiques à mafiques présents partout à l'intérieur du secteur d'étude. La granodiorite de Red Brook est une intrusion ignée composite, polyphasée, accompagnée de dykes, de filons-couches et d'apophysees connexes qui sont génétiquement liées aux gîtes de skarns cuprifères près de la limite occidentale de l'intrusion. La granodiorite de Red Brook est typique des intrusions de type I calco-alcalines communément associées aux marges des plaques convergentes. Deux populations de dykes et de filons-couches sont présentes: des microgranites ayant des compositions extrêmement felsiques et des signatures d'éléments traces semblables à celles du type A, des granites intra-plaque et des porphyres feldspathiques intermédiaires qui sont chimiquement identiques à la granodiorite de Red Brook. Les porphyres feldspathiques sont interprétés comme des éléments comagnatiques de la granodiorite de Red Brook (c.-à-d. du Dévonien moyen), tandis que les microgranites ressemblent sur le plan chimique aux intrusions du Silurien tardif au Dévonien précoce du Nord du Nouveau-Brunswick et qu'ils pourraient par conséquent être beaucoup plus âgés que les porphyres feldspathiques. Une vaste zone d'altération métasomatique de contact (skarns, cornéennes et porcélanite) dans les formations de White Head et d'Upsalquitch, près de la marge occidentale de la granodiorite de Red Brook, abrite une minéralisation de cuivre à faible teneur à l'emplacement du gîte de Popelogan. Les réserves ont été estimées à 3 millions de tonnes de 0,3 % de Cu. Une altération de porcélanite du genre de celle du gîte de Popelogan a également été observée dans la Formation d'Upsalquitch, dans la partie orientale du secteur d'étude, où elle constitue au moins 5 % d'une section stratigraphique de 100 m le long du ruisseau Narrows. Les roches volcanomafiques de la Formation de Goulette Brook renferment plusieurs venues de métaux communs, dont un intervalle de 7 m ayant titré 1,14 % de Zn et 0,12 % de Cu dans un trou récemment foré au sud-ouest du gîte Popelogan.

INTRODUCTION

Geological mapping in Restigouche County has been undertaken in order to acquire an improved understanding of the geology and mineral potential of the Gaspé Belt in New Brunswick. The Restigouche Project represents the New Brunswick contribution to the Appalachian Foreland and Platform Project, which is the NATMAP-funded component of a multi-agency, multi-disciplinary effort known as Geological Bridges of Eastern Canada. The "bridges" consist of several geological transects across the St. Lawrence Platform, the Appalachian foreland thrust–fold belt, and Middle to Late Paleozoic successor basins, including the Late Ordovician–Middle Devonian Gaspé Belt. Two of these transects extend into northern New Brunswick (Figure 1); hence, provincial mapping and thematic studies benefit from the shared objectives and methodologies of ongoing programs in Québec. Combined, these studies will help elucidate the overall architecture and geological history (origin, sedimentation, deformation and exhumation) of the Gaspé successor basin.

The Gaspé Belt is interpreted as a syn-collisional fore-arc basin formed on the Laurentian margin during northwestward subduction of the Tetagouche–Exploits back-arc oceanic tract (van Staal and de Roo 1995). However, the stratigraphic, tectonic, metamorphic and magmatic history of the belt are poorly understood, especially in New Brunswick. Specific objectives of the projected 5-year mapping program include: (1) investigation of the nature of the basement underlying the Gaspé Belt; (2) lithostratigraphy, sedimentology, facies distribution and provenance of sedimentary rocks; (3) identification of extensional/

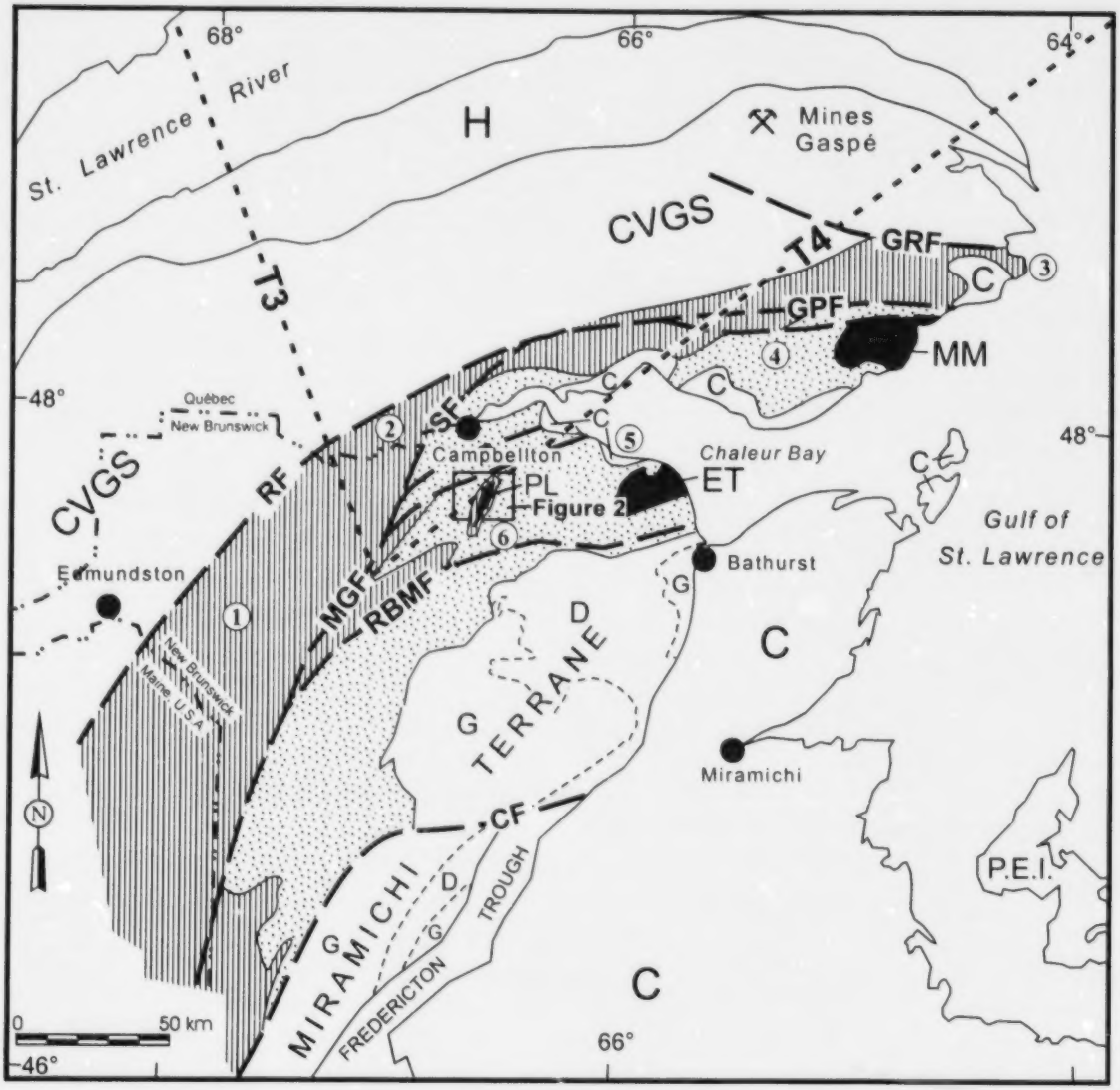


Figure 1. Major geological divisions of northern New Brunswick and Gaspé, Québec, showing location of Popelogan Lake–Lost Pine Lake area (Figure 2). The Aroostook–Percé Anticlinorium is shown in vertical hatching, and the Chaleur Bay Synclinorium in stipple pattern. Numbers refer to locations of stratigraphic columns presented in Figure 5: ①—Siegas–northwestern New Brunswick; ②—Matapédia, Québec; ③—Percé, Québec; ④—Honorat–Mictaw, Québec; ⑤—Chaleur Bay, New Brunswick; ⑥—Popelogan area, New Brunswick. Dark-shaded areas are inliers that predate Late Ordovician to Middle Devonian rock of the Gaspé Belt: **MM**—Macquereau–Mictaw inlier (Dunnage and Humber zones); **ET**—Elmtree inlier (Dunnage Zone); **PL**—Popelogan inlier (Dunnage Zone). **H**—Humber Zone; **CVGS**—Connecticut Valley–Gaspé Synclinorium; **G**, **D**—Gander and Dunnage zone rocks, respectively, in the Miramichi Terrane; **C**—Carboniferous cover. Major faults: **CF**—Catamaran Brook Fault; **RBMF**—Rocky Brook–Millstream Fault; **MGF**—McKenzie Gulch Fault; **RF**—Restigouche Fault; **SF**—Sellarsville Fault; **GPF**—Grand Pabos Fault; **GRF**—Grande Rivière Fault. **T3**, **T4**—transects 3 and 4 of the NATMAP/Geological Bridges of Eastern Canada program.

compressional events, unconformities, disconformities, etc.; (4) metamorphism and thermal maturation; (5) style and timing of deformational events; and (6) the age, chemistry and petrogenesis of igneous rocks. This paper presents, first, the results of preliminary field investigations carried out in the Popelogan Lake–Lost Pine Lake area in the eastern part of the Gaspé Belt (Figure 1), and second, a review of some of the relevant literature pertaining to regional tectonic evolution, stratigraphy, age relationships and correlation of rock units within the Gaspé Belt.

REGIONAL GEOLOGY AND PREVIOUS WORK

The Gaspé Belt extends from eastern Gaspé Peninsula in Québec, southwestward through northwestern New Brunswick to northeastern USA (Figure 1). The Gaspé Belt constitutes a successor basin that has a complex history; parts of the basin have experienced at least one major upheaval during the Silurian, as evidenced by a widespread unconformity in the Late Silurian–Early Devonian (Alcock 1935; "Salinic disturbance" of Boucot *et al.* 1964, Malo and Bourque 1993, van Staal and de Roo 1995). The basin conceals and overlaps the boundary between the Avalonian and Laurentian margins, represented respectively by rocks of the Miramichi Terrane in New Brunswick (Gander Zone and fragments of Dunnage Zone) and the "nappe domain" in Québec (Humber Zone) (Figure 1). Basement to the successor basin is interpreted to consist of Dunnage Zone rocks (e.g., van Staal and de Roo 1995; Malo and Bourque 1993), represented in New Brunswick by the Popelogan Inlier (ensialic arc volcanic rocks) and Elmtree Inlier (oceanic crust), and in Québec by the Macquereau–Mictaw Inlier (Figure 1). The Gaspé Belt encompasses Upper Ordovician to Middle Devonian rocks that belong to one of three major structural divisions, namely, from northwest to southeast, the Connecticut Valley–Gaspé Synclinorium, the Aroostook–Percé Anticlinorium, and the Chaleur Bay Synclinorium (Rodgers 1970, modified by Malo 1988 and Malo and Bourque 1993) (Figure 1).

The Popelogan Lake–Lost Pine Lake area overlaps rocks affiliated with the Aroostook–Percé Anticlinorium and Chaleur Bay Synclinorium south of the city of Campbellton (Figure 1). The Aroostook–Percé Anticlinorium extends from Percé to Matapédia in the Gaspé Peninsula, thence across northwestern New Brunswick to Aroostook County in northeastern Maine. Upper Ordovician to Lower Silurian rocks of the Aroostook–Percé Anticlinorium comprise deep-water turbidite deposits, including a lower siliciclastic assemblage and an upper carbonate assemblage. The siliciclastic rocks have been assigned to the Honorat Group in Québec (Skidmore 1965) and the Grog Brook Group in northwestern New Brunswick (St. Peter 1978), whereas the carbonate assemblage has been assigned to the Matapédia Group (Crickmay 1932; Alcock 1935; Lespérance *et al.* 1987). The Honorat and Matapédia groups unconformably overlie Middle to Upper Ordovician rocks of the Mictaw Group (Macquereau–Mictaw Inlier) in the Gaspé Peninsula (Malo and Bourque 1993; Tremblay *et al.* 1993) and the Balmoral and Fournier groups (Popelogan and Elmtree inliers, respectively) in northern New Brunswick (van Staal *et al.* 1998). This Ordovician hiatus has been related to uplift caused by collision of the Popelogan arc with Laurentia during Caradocian time (van Staal *et al.* 1991; van Staal *et al.* 1998). The contact between the Aroostook–Percé belt, and overlying Silurian to Devonian rocks of the Connecticut Valley–Gaspé Synclinorium and Chaleur Bay Synclinorium, is conformable (e.g., St. Peter 1978; Bourque *et al.* 1995), although in many places the zones are juxtaposed along major dextral strike-slip faults such as the Rocky Brook–Millstream Fault (Figure 1).

The Chaleur Bay Synclinorium extends from the southeastern part of the Gaspé Peninsula, southwest to west-central New Brunswick (Figure 1), and consists of Silurian to lowermost Devonian sedimentary and volcanic rocks of the Chaleurs Group (Schuchert and Dart 1926; Burk 1964), and Lower to Middle Devonian sedimentary and volcanic rocks of the Dalhousie Group (Clarke 1909; Greiner 1967). Both the

Chaleurs and Dalhousie groups are characterized by abrupt lateral changes in lithology and sedimentary facies, indicating a complex paleogeography and tectonic history. To help understand this history, the Chaleur Bay Synclinorium has been divided into a number of subsidiary structural "blocks" that feature contrasting stratigraphy (Walker and McCutcheon 1995); one of these domains encompasses the Popelogan Lake–Lost Pine Lake area, where the dominant structural feature is the Popelogan Anticline (Figures 1 and 2). On the southeastern margin of the Chaleur Bay Synclinorium, the Chaleurs Group unconformably overlies Ordovician rocks (Fournier Group) of the Miramichi Terrane and Elmtree Inlier (e.g., Alcock 1935; Helmstaedt 1971; Walker *et al.* 1993; Walker and McCutcheon 1995).

Mapping of the Gaspé Belt in Québec has been carried out in some detail, and comprehensive reviews have been presented by Bourque *et al.* (1995) and Bourque *et al.* (2000). However, in northern New Brunswick, the database is much less complete, and some areas remain essentially unmapped. Reports on the geology of parts of the Gaspé Belt in New Brunswick have been produced by Alcock (1935), St. Peter (1978), Hamilton-Smith (1970), and Irrinki (1990). Geological maps of parts of the Gaspé Belt also have been published by Potter (1965) for the Upsalquitch Forks area (NTS 21 O/10), and Greiner (1970, 1974) for the Charlo and Campbellton areas (NTS 21 O/16, 21 O/15, respectively). Previous mapping in the Popelogan Lake–Lost Pine Lake area has been carried out at a scale of one-quarter mile to the inch by Constable (1973a, b) and Irrinki (1973, 1974); the latter also published a 1:50 000 scale geological map of the northern part of the Chaleur Bay Synclinorium (Irrinki 1976). Stratigraphic, paleontological, and paleoenvironmental thematic studies were carried out in the Charlo–Upsalquitch area by Lee and Noble (1977) and Noble and Howells (1979). More recently, geological and metallogenic investigations have been carried out by Philpott (1987, 1988); however, 1:20 000 scale geology maps produced at this time (Philpott 1990a, b) did not improve on the earlier mapping. Following the release of multi-sensor, high-resolution airborne geophysical data from the Restigouche area (Kiss 1998), ground follow-up of anomalies and mineral occurrences was carried out by Giggie (1999), who also produced a 1:100 000 compilation of previous geological mapping over much of the Gaspé Belt of northern New Brunswick (Giggie 1998).

DESCRIPTION OF STRATIGRAPHIC UNITS

Field investigations in 1999 have led to several revisions and reinterpretations of the geology of the Popelogan Lake–Lost Pine Lake area (Figure 2). Geological maps of this area have also been published at 1:20 000 scale (Wilson 2000a, b). The oldest rocks are arc-related mafic flows and pyroclastic rocks of the Middle to Late Ordovician Goulette Brook Formation (Irrinki 1976), representing one of the few exposed fragments of the Popelogan Terrane. The Goulette Brook Formation is locally, and possibly disconformably, overlain by Caradocian, graptolitic, black slates and cherts of the Popelogan Formation (Philpott 1988). Together, these units constitute the Balmoral Group and make up the core of the Popelogan Anticline (Figure 2). The Balmoral Group is disconformably overlain by Ashgillian to lower Llandoverian calcareous rocks of the Matapédia Group, which in turn are gradationally overlain by lower Llandoverian to earliest Wenlockian, calcareous sedimentary rocks of the Upsalquitch Formation (St. Peter 1978). In the Popelogan area, the Upsalquitch Formation represents the basal unit of the Chaleurs Group (Walker and McCutcheon 1995). In the southeast part of the survey area, the Upsalquitch Formation is juxtaposed against volcanic rocks of the Chaleurs Group (Bryant Point and Benjamin formations) along an interpreted strike-slip fault.

Balmoral Group

Goulette Brook Formation: The Goulette Brook Formation crops out along Goulette Brook and one of its tributaries near the nose of the Popelogan Anticline, and on two small streams draining the eastern

flank of the anticline, but most outcrops are found along old and new bush roads southeast of Indian Lake in the central part of the survey area. The base of the Goulette Brook Formation is not exposed, hence no estimate of thickness is possible. Based on the relative proportion of exposures, the Goulette Brook Formation consists mainly of basaltic lapilli tuffs and agglomerates that contain abundant secondary (interstitial) calcite (Figure 3a), whereas massive to very amygdaloidal basaltic flows are less widespread. The spatial distribution of respective lithotypes suggests that the tuffs and lavas are interbedded, although the number of individual beds of each is unclear, and that the massive to amygdaloidal basalt flows are most common in the central part of the Popelogan Anticline where the oldest rocks would be expected. Philpott (1988) has proposed an upper lapilli tuff member and a lower "ultramafic hyaloclastite" member, apparently based on core from one drill hole on the western flank of the anticline, 1.2 km south of Goulette Brook and 500 m southwest of the Goulette Brook mineral occurrence (Tauchid 1970) (Figure 2). However, examination of thin sections from the upper 500 feet (152 m) of drill core has shown that these rocks are actually amygdaloidal basalts. Hence, in the west limb of the Popelogan Anticline, amygdaloidal basalt overlies and underlies a relatively thick sequence of pyroclastic rocks. This is in agreement with Moorhouse (1955), who mapped the Little Popelogan Brook area to the south for American Metals Company Ltd., and described carbonate-cemented agglomeratic tuff overlain and underlain by vesicular [sic] basalt. (Moorhouse (1955) also correctly interpreted the local stratigraphic succession as consisting of (in order of younging) mafic volcanic rocks, dark grey to black chert, and limestones interbedded with shales). Notwithstanding the above, it is clear that, in places, the youngest rocks in the Goulette Brook Formation are lapilli tuffs and agglomerates, e.g., on the eastern limb of the Popelogan Anticline and in the southern part of the survey area.

Petrographically, the lapilli tuffs/agglomerates consist of rounded, angular, or "feathery" clasts of amygdaloidal to scoriaceous, typically hyalopilitic, locally intergranular or porphyritic basalt set in a carbonate-rich matrix (Figure 3b). Many clasts have been extensively to totally replaced by chlorite; commonly, the chlorite is a pale green, oolitic or "spherulitic" variety that is probably chamosite. Zeolites are relatively abundant in a number of thin sections, occupying vesicles and other cavities; typically, they occur as a fibrous or sheaf-like species, probably natrolite, although stilbite has been identified in a few sections. Zeolites in basaltic tuffs of the Goulette Brook Formation have also been reported by Irrinki (1990). Other constituents include recrystallized, fine-grained aggregates of albite, Fe–Ti oxides, and, rarely, epidote and quartz. Petrographic and textural evidence from thin sections does not support the presence of hyaloclastites (formed by quench-shattering and granulation of hot lava in water) or palagonite tuffs (i.e., altered hyaloclastites) as reported by Philpott (1988) and Irrinki (1990), respectively. Instead, the Goulette Brook fragmental rocks that have been examined all appear to have a pyroclastic origin, based on rounded to ragged (as opposed to angular) clast shape, diverse clast lithology, and the local presence of small lapilli enclosed in larger lapilli. In places, the carbonate matrix of the tuffs has been removed by weathering, leaving the rock crumbly, porous, and rusty brown in colour; i.e., it resembles a gossan, but is not associated with sulphide mineralization. However, low-grade base-metal mineralization is locally hosted by the Goulette Brook Formation (Tauchid 1970; Moore 1999), so some gossans may indicate the presence of sulphides.

Basaltic flows are massive to very amygdaloidal, and exhibit the same textural styles as basalt clasts in the lapilli tuffs. Most have hyalopilitic texture, consisting of randomly oriented plagioclase microlites in a turbid or chloritic mesostasis, but some have coarser-grained, intersertal to (rarely) intergranular textures. Euhedral plagioclase phenocrysts up to 2.5 mm, altered in varying degrees to calcite, chlorite, and rarely quartz, are commonly (though not always) present, in amounts ranging up to 10%. Amygdules vary in abundance up to about 30%, and range in size from less than 0.5 mm up to large, irregular, coalesced

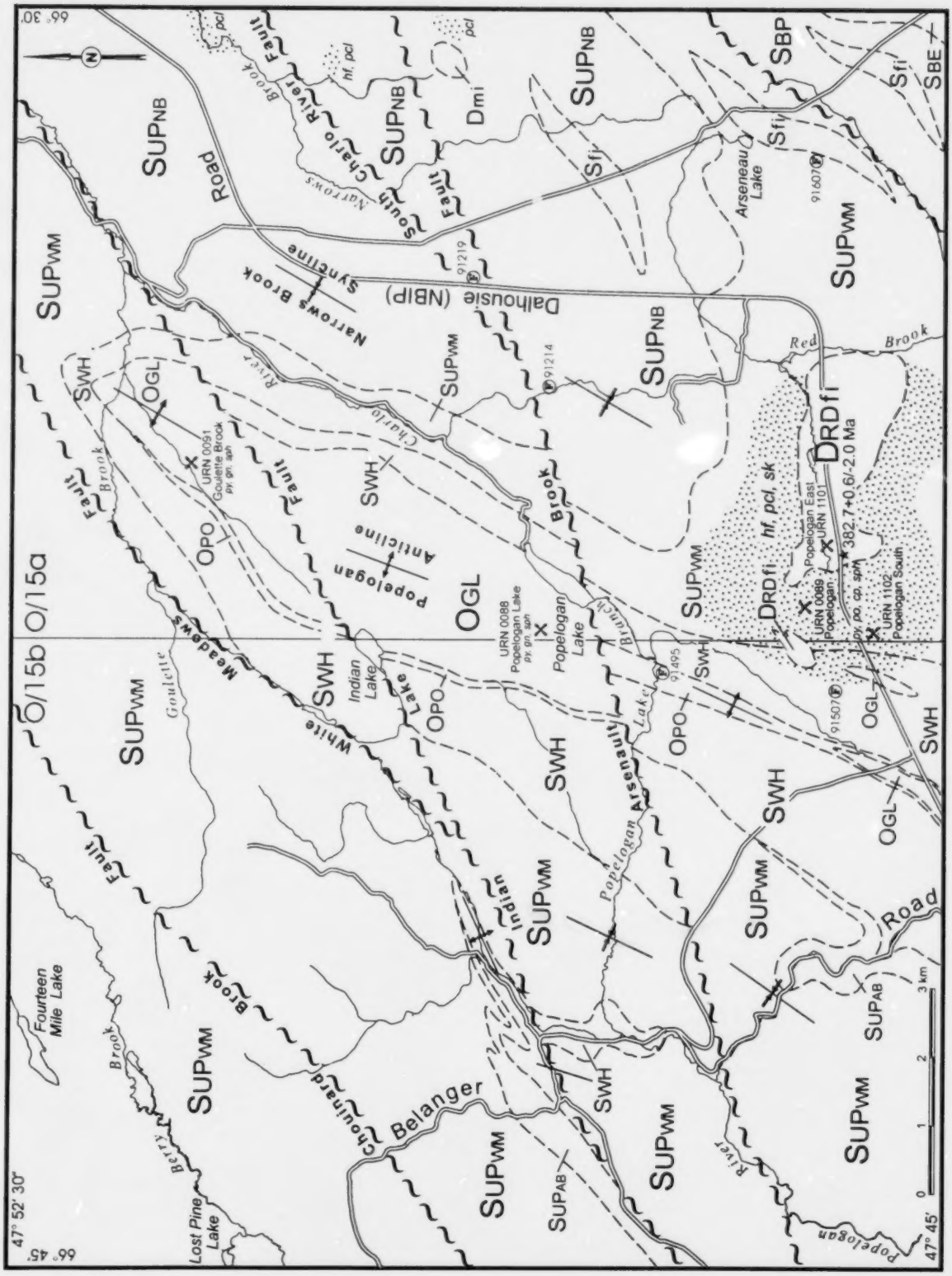


Figure 2. Geological map of the Popelogan Lake–Lost Pine Lake area. Metasomatically altered rocks are shown in grey stipple pattern.

LEGEND (Figure 2)

DEVONIAN

DRDfi — **Red Brook Granodiorite**: Grey to greyish pink, medium- to coarse-grained quartz monzonite, granodiorite and granite

Dmi — Grey, medium-grained diorite

SILURIAN

Sfi — Pink to brick-red felsite and fine-grained feldspar porphyry

EARLY–LATE SILURIAN

Chaleurs Group

SBE — **Benjamin Formation**: Pink flow-banded rhyolite

SBP — **Bryant Point Formation**: Amygdaloidal, locally porphyritic basalt

SUP — **Upsalquitch Formation**: Narrows Brook member (SUPNB)—Thin-bedded, micaceous, commonly bioturbated and fossiliferous, non-calcareous to weakly calcareous siltstone and fine-grained sandstone; local thin beds of calcarenite. White Meadows member (SUPWM)—Thin-bedded, slightly micaceous, commonly bioturbated and fossiliferous, coarse-grained calcilutite gradational to calcareous siltstone, minor calcarenite and shale. Arsenault Brook member (SUPAB)—Thin- to medium-bedded, fine- to medium-grained micaceous calcarenite gradational to calcareous sandstone and siltstone.

EARLY SILURIAN

Matapédia Group

SWH — **White Head Formation** (L'Irlande Member): Mainly thin- to medium-bedded calcilutite, commonly intercalated with thin beds or laminae of calcareous shale; minor calcarenite, weakly calcareous shale, and siltstone.

MIDDLE–LATE ORDOVICIAN

Balmoral Group

OPO — **Popelogan Formation**: Black graphitic shale and chert.

OGL — **Goulette Brook Formation**: Mafic lapilli tuff containing abundant carbonate cement, and amygdaloidal to (rarely) massive mafic flows; minor hyaloclastite.

— — — — geological contact

~~~~~ fault

syncline

anticline

382.7 Ma U–Pb radiometric age

F 91214 fossil locality with GSC location number

URN 0089 mineral occurrence with Unique Record Number
py—pyrite; po—pyrrhotite; ga—galena; sph—sphalerite; cp—chalcopyrite

hf, pcl, sk—hornfels, porcellanite, skarn
~~~~~

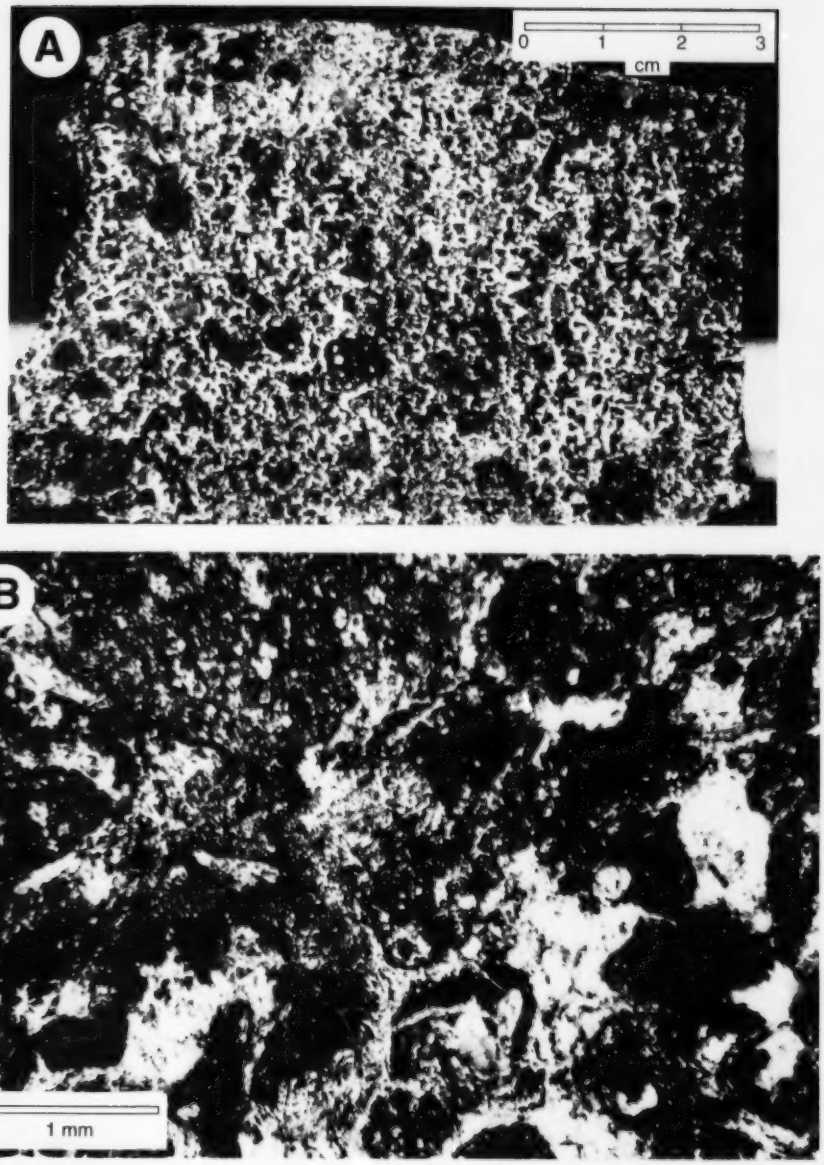


Figure 3. (a) Hand specimen of carbonate-cemented, basaltic lapilli tuff of the Goulette Brook Formation. (b) Photomicrograph (plane-polarized light) of mafic lapilli tuff of the Goulette Brook Formation. Field of view is 5 mm.

cavities exceeding 1 cm. Amygdules are typically filled with chlorite, calcite, and/or zeolites. The presence of zeolites, and absence of prehnite, pumpellyite or any higher-grade metamorphic minerals in the Goulette Brook Formation, indicates that these rocks were subjected to low regional temperatures consistent with shallow burial. Zeolite facies metamorphism has previously been reported in Silurian and Devonian mafic volcanic rocks at Middle Brook to the east, and near Dalhousie to the northeast of the survey area (Mossman and Bachinski 1972).

Popelogan Formation: The Goulette Brook Formation is locally overlain by black shales and cherts of the Popelogan Formation, which is poorly exposed in scattered outcrop and subcrop on the west limb of

the Popelogan Anticline, and along Popelogan Lake Branch, where it forms the core of the anticline (Figure 2). It has also been intersected in the above-mentioned drillhole south of Goulette Brook, where the Goulette Brook Formation is overlain by 9 m of greenish grey chert followed by 50 m of graphitic shale and siltstone (Tauchid 1970). By far the best exposures are present in a road-metal quarry on the NBIP Road just to the south of the survey area. Here, the Popelogan Formation contains graptolites that have been assigned to the *Nemagraptus gracilis* zone, corresponding to the early Caradocian (GSC location 102397, identifications by J. Riva, in Philpott 1987). Graptolites recovered from a road outcrop just south of Popelogan Lake Branch (GSC location 91495, Figure 2) have similarly been assigned to the *N. gracilis* zone (identifications by J. Riva, personal communication to L. Fyffe, 1987).

When the rock quarry was last visited in 1999, the contact between the Popelogan Formation and Goulette Brook Formation was exposed by recent excavations. The top of the Goulette Brook Formation is marked by a 2–3 m-thick magnetite-rich zone, oxidized to hematite near the contact. It is not clear whether or not this oxidized zone marks a disconformity; if not, the implication is that arc volcanism persisted in the Popelogan Terrane long after rifting of the Popelogan arc led to the opening of the Tetagouche–Exploits back-arc basin (van Staal *et al.* 1998). The Popelogan Formation is overlain in the quarry by a thin unit of greyish green silty mudstone, followed by calcareous rocks of the Matapédia Group; contacts are unexposed but are believed to be conformable. In places, the Popelogan Formation is absent; for example, on the east limb of the Popelogan Anticline, the Matapédia Group disconformably overlies the Goulette Brook Formation, with no intervening black shale or chert (this contact is exposed on a trail parallel to a small brook flowing east to Charlo River; see Figure 5 in Irrinki 1990). A narrow zone of calcareous breccia or conglomerate at the contact contains a few pebbles of chert, indicating erosive removal of the Popelogan Formation.

Matapédia Group

White Head Formation: The Matapédia Group is exposed on the flanks of the Popelogan Anticline between Goulette Brook and the NBIP Road. Just west of the anticline, an "inlier" of Matapédia rocks is situated along the Belanger Road in the valleys of upper Popelogan River and lower Arsenault Brook (Figure 2); the latter is evidently a manifestation of topography rather than bedrock structure. The Matapédia Group comprises two lithofacies in the survey area, a stratigraphically lower, thin-bedded calcilutite–calcareous shale facies, and an upper, massive to thin-bedded, silty or argillaceous calcilutite facies (terminology follows the classification of Grabau 1903). The former is mainly exposed on the eastern limb of the Popelogan Anticline, where the total thickness of the Matapédia Group is as little as 150 m, and the "upper" facies is either unexposed or not present. On the west limb, the thickness appears to be greater, although the effect of possible structural repetition by minor folds is unclear because of limited exposure. The calcilutite–calcareous shale facies is characterized by thin (4–8 cm), very uniform beds of dark bluish grey calcilutite interbedded with partings and thin beds (up to 2 cm) of silty, slightly to moderately calcareous shale (Figure 4a). The massive calcilutite facies is best exposed on the Belanger Road in the headwaters of Popelogan River, and consists mainly of massive to subtly bedded or laminated, dark bluish grey, variably argillaceous calcilutite (Figure 4b), and minor calcareous siltstone and fine-grained calcarenite. Moderately calcareous to noncalcareous, greyish green silty shale constitutes a minor lithotype seen only in a few outcrops; it is unclear whether it is interbedded with the calcilutite–calcareous shale facies, or separates the latter from the overlying massive calcilutite facies. Petrographically, calcilutites in all areas are similar, consisting mainly of clay-sized carbonate grains, fine-silt-sized grains of quartz and feldspar (typically 5–10%), local comminuted fossil debris, scattered tiny muscovite flakes, and carbonate veinlets or micro-veinlets. Clay minerals are apparently present in variable amounts, based on differential weathering on outcrop surfaces; however, at the grain-size range of these rocks, clay minerals

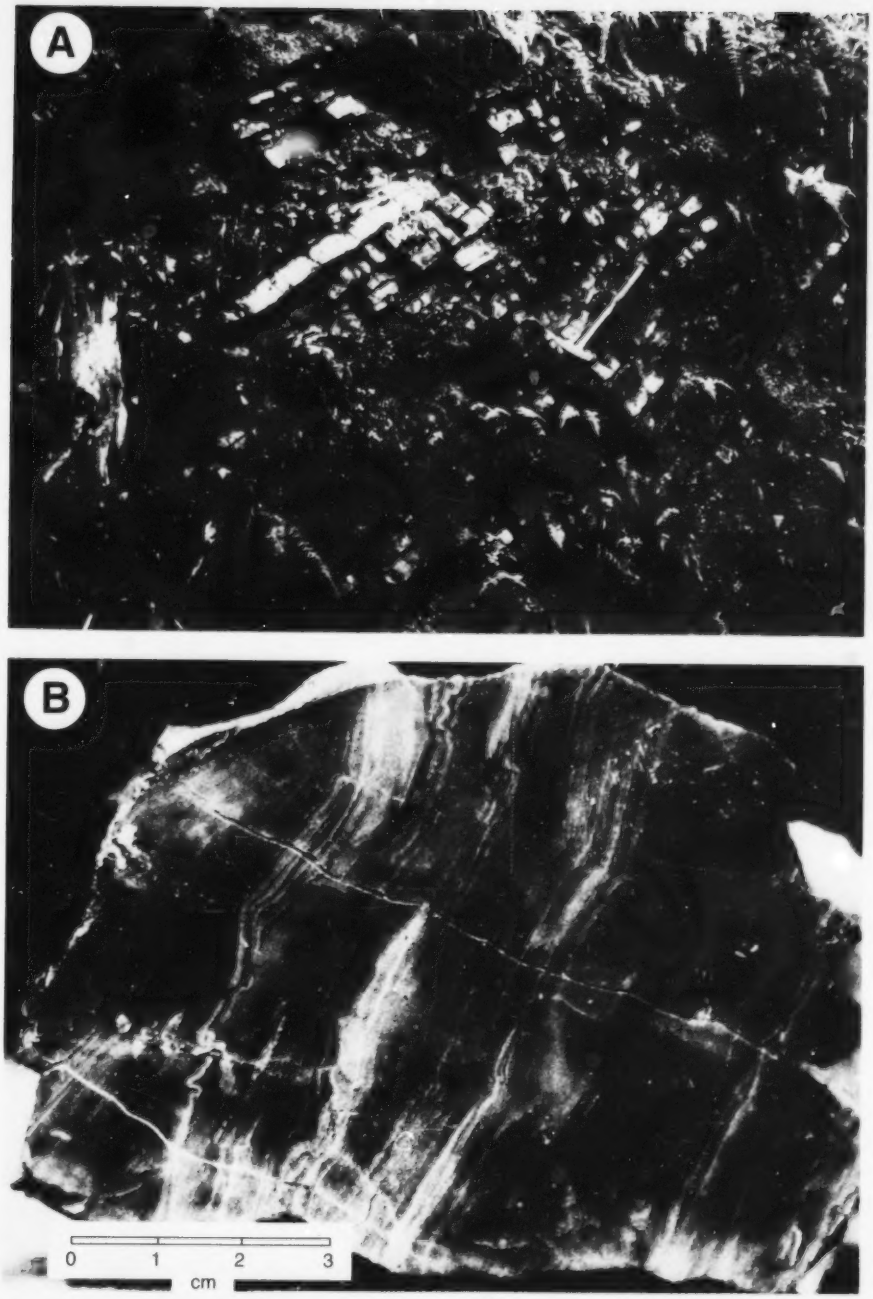


Figure 4. (a) White Head Formation, Matapédia Group, north-northeast of Popelogan Lake, illustrating uniform thin beds (4–8 cm) of calcilutite interbedded with thin (up to 2 cm) partings of calcareous shale. Hammer at right-centre is 40 cm long. (b) Laminated calcilutite of the White Head Formation on Belanger Road near the mouth of Popelogan Lake Branch. Thin white laminae consist of fine-grained calcarenite.

are very difficult to distinguish from clay-sized carbonate, and percentages are difficult to estimate.

Lithotypes and bedforms in the upper part of the Matapédia Group are transitional to those observed in the overlying Upsalquitch Formation. For example, thin beds and laminae of fine-grained calcarenite (Figure 4b) are locally abundant in the massive calcilutite facies, and commonly exhibit parallel and cross-lamination and local bioturbation. This, along with a generally higher abundance of terrigenous grains (locally up to 30%) compared to the calcilutite–calcareous shale facies, signals the transition to shallower-water rocks of the Upsalquitch Formation.

Regionally, the dominant lithotype in the Matapédia Group is consistently described as laminated to thin-bedded, calcitic to ankeritic, argillaceous limestone and calcareous shale/mudstone, with minor fine-grained calcarenite and non-calcareous shale or siltstone (e.g., Pavlides 1968; Ayrton *et al.* 1969; Hamilton-Smith 1970; Roy and Mencher 1976; St. Peter 1978; Stringer and Pickerill 1980; Pickerill *et al.* 1987; Malo 1988; Wilson 1990). Although the carbonate rocks have generally been described as argillaceous limestones, this writer prefers the term calcilutite (Grabau 1903), which specifies deep-water deposits of silt- to clay-size detrital calcite presumably eroded from a contemporaneous carbonate platform, and avoids the connotation of in-situ biogenic deposits. Sedimentary structures and bedforms in the Matapédia Group, e.g., graded bedding, parallel and cross-lamination, local convolute bedding, and load and flute casts, are typical of deposits laid down by decelerating, turbiditic flows (e.g., Pavlides 1968; Ayrton *et al.* 1969; St. Peter 1978). A deep-water, bathyal or abyssal setting (up to 600 m depth) for the Matapédia Group was proposed by St. Peter (1978), whereas Lespérance *et al.* (1987) identified in-situ faunal communities typical of Benthic Assemblage 6 (Boucot 1975) in correlative rocks in the Percé area, Québec. They suggested water depths no greater than 200 m, although it was observed that Matapédia rocks in the Percé area appear to have been deposited in shallower water compared to other strata in the Aroostook–Percé Anticlinorium, i.e., there is a northeast-to-southwest, proxoimal to distal facies zonation in the Matapédia Group (e.g., Bourque *et al.* 2000). Pickerill *et al.* (1987) postulated deposition above the calcite compensation depth (shallower than bathyal or abyssal conditions), and Stringer and Pickerill (1980) favoured deposition on a slope by hemipelagic and bottom-following contour currents with periodic introduction of turbidite deposits. The presumed source of the calcareous detritus, based on facies zonation, paleocurrent analysis, and similarity in conodont fauna, is the Anticosti platform to the north and northeast (Nowlan 1981; Lespérance *et al.* 1987; Malo 1988). However, conodonts representative of Midcontinent Province communities suggest provenance, at least in part, from the west (Nowlan 1983).

Age and regional correlation: Regionally, the Matapédia Group shows remarkable lithological homogeneity; however, in the Gaspé Peninsula, subtle but consistent lithologic variations in the stratigraphic sequence have allowed the recognition of formations and members (Lespérance *et al.* 1987). Hence, in the Percé area, the Matapédia Group has been divided into the Pabos Formation and overlying White Head Formation; the latter includes, in order of younging, the Burmingham, Côte de la Surprise, L'Irlande and Des Jean members (Skidmore and Lespérance 1981; Lespérance *et al.* 1987) (Figure 5). This stratigraphic scheme has been extended to other parts of the Gaspé Peninsula by Malo (1988). These units range in age from early Ashgillian, to early or late Llandoverian; i.e., the upper age limit varies from place to place (Figure 5). It is proposed, in the interests of a unified nomenclature and to facilitate comparisons with the Gaspé section, that terminology defined in Québec should be applied, where possible, to rocks of the Matapédia Group in New Brunswick. Accordingly, it can be demonstrated, as explained below, that Matapédia rocks in the Popelogan area should be assigned to the L'Irlande Member of the White Head Formation.

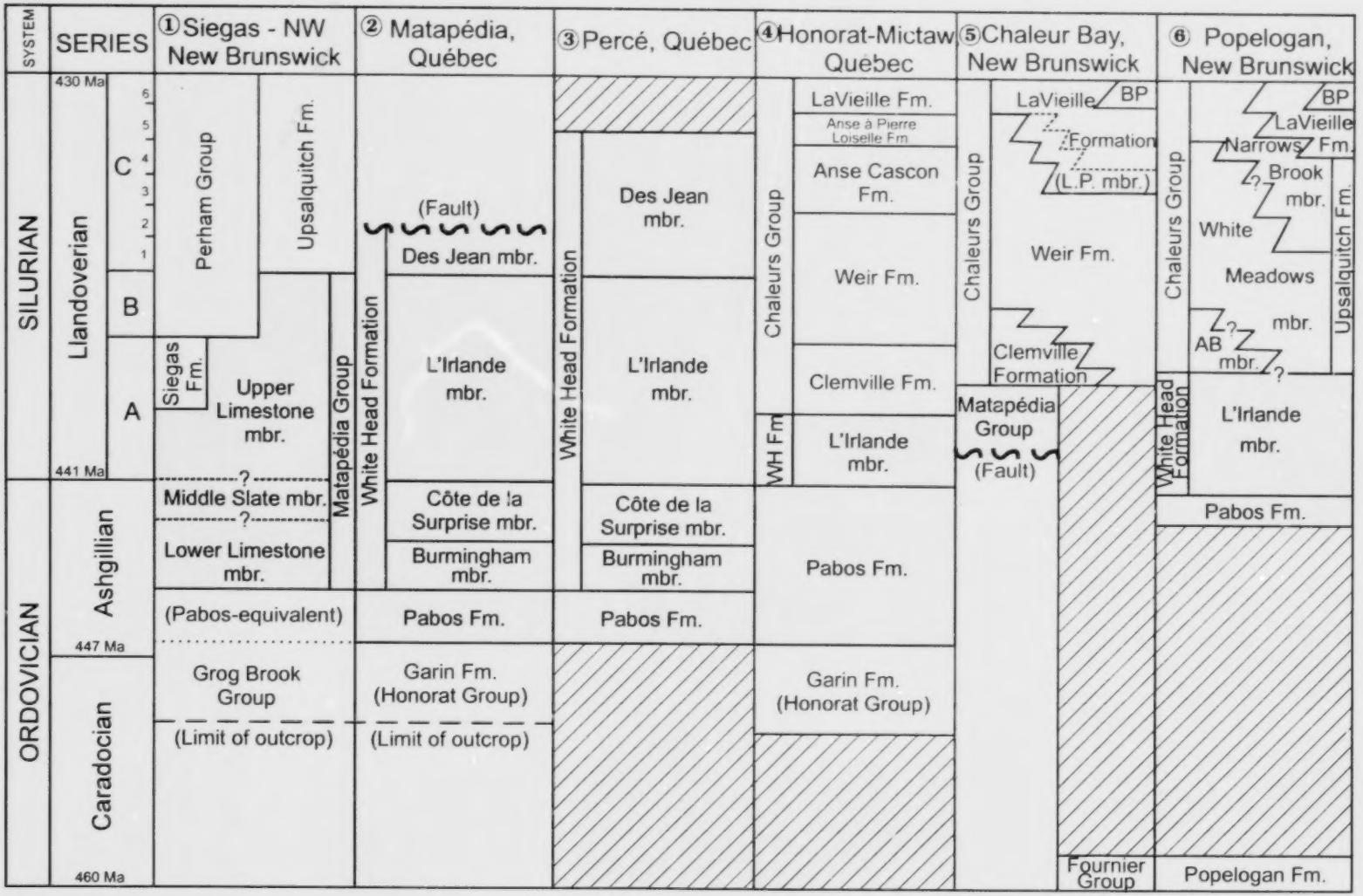


Figure 5. Stratigraphic columns for different parts of the Gaspé Belt in New Brunswick and Québec; see Figure 1 for locations. Cross-hatching—unconformity or disconformity; shaded area—Matapédia Group. Abbreviations: **AB**—Arseneault Brook member; **BP**—Bryant Point Formation. Sources of data include Hamilton-Smith (1970), Bourque (1975), Noble (1976), Lee and Noble (1977), St. Peter (1978), Bourque and Lachambre (1980), Malo (1988), Irrinki (1990), Walker and McCutcheon (1995), and Bourque *et al.* (1995). Time scale is from Okulitch (1999).

The Pabos Formation is largely a terrigenous unit (calcareous and noncalcareous mudstones and siltstones, argillaceous limestone, and sandstone), and includes rocks that in New Brunswick are assigned to the upper part of the Grog Brook Group. The latter underlies and may be laterally equivalent to the lower part of the Matapédia Group in northwestern New Brunswick (St. Peter 1978; Nowlan 1983). In the White Head Formation, the Burmingham Member (middle Ashgillian) and L'Irlande Member (early Llandoverian) are lithologically identical, and dominantly consist of thin-bedded calcilutite and calcareous shale, with minor calcarenite. The intervening Côte de la Surprise Member (latest Ashgillian) consists of dark green calcareous mudstone and minor quartz arenite. The Des Jean Member, at the top of the sequence, is more variable, comprising thin- to thick-bedded calcarenite and calcilutite, and thin-bedded silty-argillaceous limestone and calcareous shale. Although members have not been formally named elsewhere, a similar succession of thin-bedded carbonates overlying and underlying noncalcareous shales has been reported in the Matapédia Group in northwestern New Brunswick (Hamilton-Smith 1970; St. Peter 1978) (Figure 5), and in northeastern Maine, where these rocks are assigned to the Carys Mills Formation (Pavlides 1965, 1968).

In the survey area, the Grog Brook Group and Pabos Formation are absent, and the Balmoral Group is disconformably overlain by Matapédia rocks that resemble the Burmingham and L'Irlande members of the White Head Formation in the type area. Similarly, local exposures of greyish green, weakly calcareous shales may correlate with the Côte de la Surprise Member. However, given the limited thickness of the Matapédia Group in the survey area, it is likely that the lower part of the Matapédia is absent and that the entire section should be referred to the (early Llandoverian) L'Irlande Member, which is also reported to include some green shale in the middle of the unit stratotype (Lespérance *et al.* 1987). Sparse fossil data and regional considerations support this view. For example, 3.5 km south of the quarry referred to above, medium- to coarse-grained grit and sandstone containing minor limestone lenses disconformably overlies Goulette Brook basalt, and is overlain by carbonate rocks of the Matapédia Group. The limestone contains a diverse conodont fauna that has been assigned a latest Ashgillian age (GSC location 103008; Nowlan 1988); hence, the carbonate rocks overlying the sandstone and grit must be early Llandoverian, i.e., equivalent to the L'Irlande Member. A second, less definitive fossil collection (GSC location 91507, Figure 2) from an outcrop believed to be just below the Matapédia–Upsalquitch contact north of the NBIP Road, contains a nonspecific Silurian pre-Ludlovian brachiopod fauna. In the Popelogan area, the upper age of the Matapédia Group is constrained by Llandoverian C tc early Wenlockian fossils in the Upsalquitch Formation (see below). In the Nash Creek area, about 30 km to the northeast, the upper age is limited by Llandoverian A_{3-4} to late Llandoverian B brachiopods in the Clemville Formation, just above the Matapédia contact (A.J. Boucot, personal communication to R.R. Irrinki, 1975, 1977).

A regional perspective illustrates the parallels between the Popelogan area and the southeastern Gaspé Peninsula. On the north side of the Grand Pabos Fault in Québec, and the west side of the McKenzie Gulch Fault in New Brunswick, carbonate deposition began in the Ashgillian (e.g., Nowlan 1983; Lespérance *et al.* 1987), and all members of the White Head Formation have been recognized, at least in the Québec section (Figure 5). In contrast, in Honorat Township, south of the Grand Pabos Fault, the thickness of the carbonate sequence is as little as 150 m, and the L'Irlande Member is the only representative of the White Head Formation (Malo 1988). The L'Irlande Member conformably overlies the Pabos Formation, which has been dated as late Ashgillian in that area (Malo 1988). The Popelogan area lies on the same side of the Grand Pabos–Sellarsville–McKenzie Gulch fault system as Honorat Township in Québec (Figure 1), and, as described above, the thickness of the Matapédia Group on the east limb of the Popelogan Anticline is in places only 150 m. Because carbonate sedimentation in the Popelogan area,

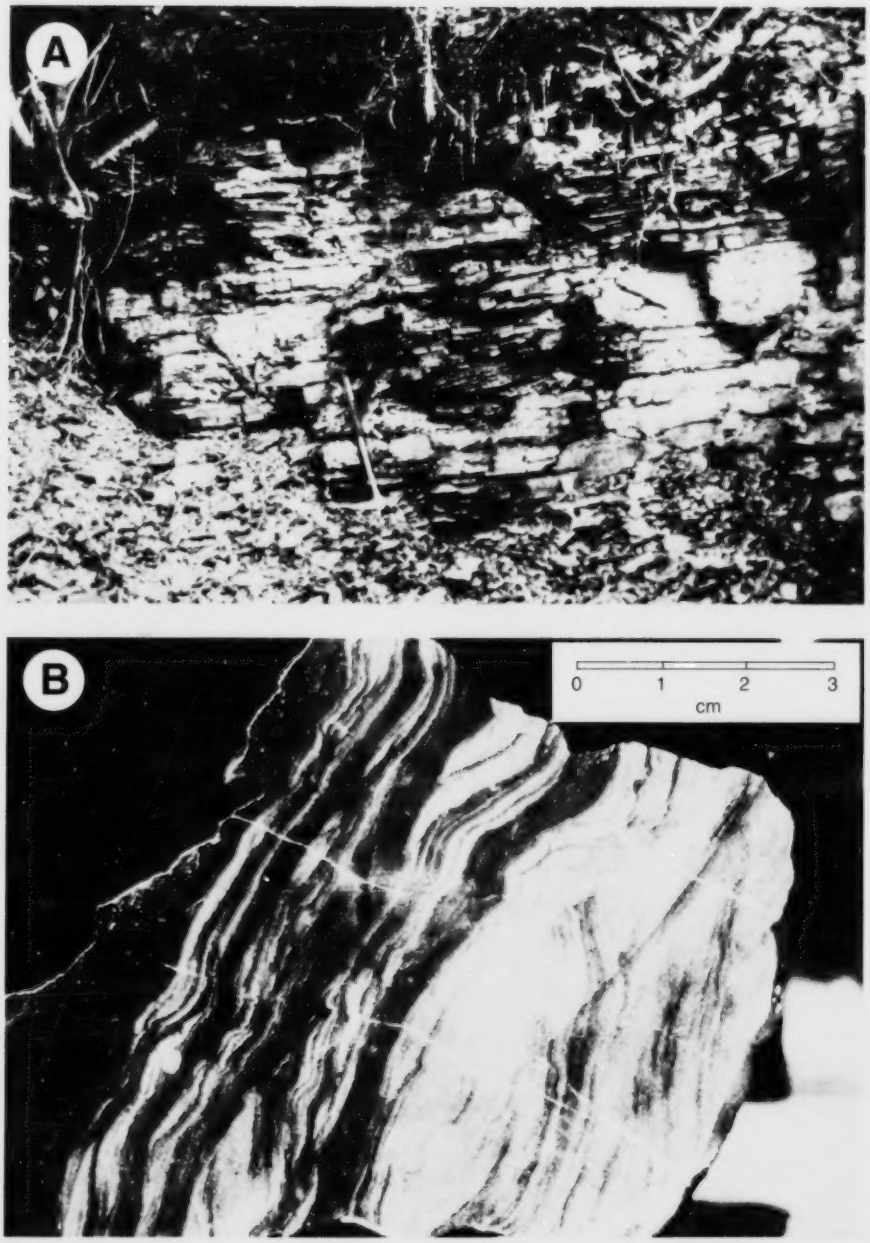


Figure 6. (a) Thin-bedded calcilutite, calcareous siltstone and shale, White Meadows member of Upsalquitch Formation, west of Belanger Road. Hammer handle is 40 m long. (b) Thin beds, lenses and laminae of cross-laminated, fine-grained calcarenite (light colour) intercalated with calcareous silty shale or siltstone (dark colour); White Meadows member of Upsalquitch Formation, east of Belanger Road near Popelogan Lake Branch.

like the Honorat area, only began in Llandoverian time, the silty mudstone in the quarry, and the limestone-bearing sandstone and grit farther south, should be assigned to the Pabos Formation. They are clearly younger than the Garin Formation of the Honorat Group (Malo 1988), which ranges in age from late Caradocian to early Ashgillian (Riva and Malo 1988).

Chaleurs Group

Lithology of the Upsalquitch Formation: The Upsalquitch Formation underlies the greater part of the survey area, and can be divided into three (informal) members: (1) the Arsenault Brook member, a discontinuous unit that is in gradational contact with the underlying White Head Formation in the southwest part of the survey area; (2) the White Meadows member, which overlies either the White Head Formation or the Arsenault Brook member; and (3) the Narrows Brook member, which overlies and, in part, is a facies equivalent of the White Meadows member (Figure 5).

The Arsenault Brook member is exposed on the Belanger Road near Arsenault Brook and headwaters of Popelogan River, where it gradationally overlies the White Head Formation (Figure 2). It consists of very thin-bedded calcareous siltstone or silty shale intercalated with thin- to medium-bedded (up to 50 cm), parallel-laminated, micaceous calcareous sandstone or calcarenite. The latter are interpreted as turbidite deposits and are the characteristic feature of this unit. The presence of minor bluish grey calcilutite, similar to that in the White Head Formation, reflects the transitional character of the Arsenault Brook member. The thickness of the Arsenault Brook member appears to be 550 m on the Belanger Road north of the White Meadows Fault; however, gaps in exposure may conceal fold closures. The maximum thickness on the Belanger Road south of the Arsenault Brook Fault is about 500 m.

The White Meadows member is the most widespread unit in the survey area (Figure 2), and comprises thin-bedded (typically 2–5 cm) calcareous siltstone that grades to coarse-grained calcilutite, with interbeds of calcareous to (rarely) noncalcareous shale and fine-grained calcarenite (Figure 6a). The latter typically occurs as brown-weathered, cross-laminated, discontinuous beds, lenses or sets of laminae 0.5 to 4.0 cm thick (Figure 6b), and less commonly as uniform, thin (3–10 cm), cross-laminated or parallel-laminated beds. Loading of very thin beds or laminae of fine-grained, parallel-laminated calcarenite in underlying dark grey calcilutite or calcareous siltstone (Figure 7a), indicates their emplacement as small-scale turbid flows. Other evidence of turbidite deposition includes truncated b–c or c–d Bouma sequences (i.e., alternating parallel-laminated and current-ripple or convolute-laminated intervals; Bouma 1962), and rhythmically alternating calcareous and noncalcareous silty laminae (cf. Lee and Noble 1977). Evidence of organic activity is widespread, manifested as bioturbated strata (Figure 7a), trace fossils on bedding surfaces, and body fossils that are particularly abundant in local thin beds that may have been deposited by turbid flows. Fossil debris identified in thin section includes fragments of trilobites, brachiopods, echinoderms (mainly crinoid ossicles), ostracodes and bryozoans (Figure 7b). In thin section, carbonate-rich beds in both the White Meadows and Arsenault Brook members contain, on average, 40% terrigenous grains (25% quartz, 14% feldspar and 1% muscovite), and 60% detrital carbonate grains. The grains are subangular to subrounded, very well sorted, and typically range in size from 0.02 to 0.15 mm (silt to very fine sand), though in some cases grains up to 0.25–0.30 mm were noted. Calcilutites grade to calcareous siltstones with an increase in the proportions of terrigenous vs. carbonate grains; some samples contain up to 30% clay matrix and may be termed argillaceous calcilutites or shaly calcareous siltstones. Commonly, all of the above lithotypes are thinly interbedded, even at thin section scale, although calcilutites and fine-grained calcarenites are volumetrically dominant. The thickness of the White Meadows member

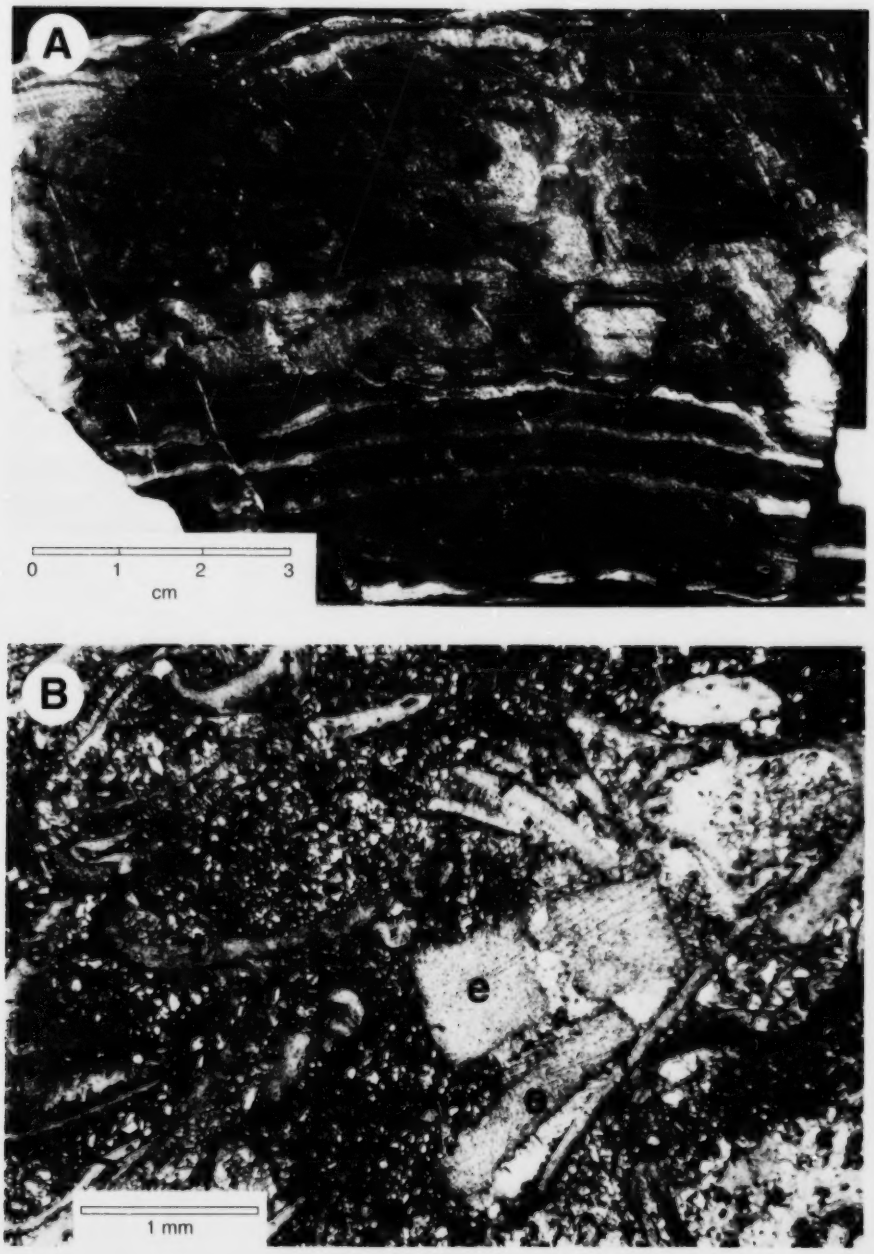


Figure 7. (a) Intense bioturbation in thin-bedded to laminated, fine-grained calcarenite (light)–calcareous siltstone (dark) rhythmite; White Meadows member of Upsalquitch Formation near Goulette Brook. (b) Photomicrograph (plane-polarized light) showing fossil debris in a fine-grained calcarenite matrix, White Meadows member of the Upsalquitch Formation near the confluence of Charlo River and Goulette Brook. Allochems compose about 40% of slide; most are trilobite (**t**) and echinoderm (**e**) fragments (probably crinoid plates). A few thin-walled ostracode carapaces (**o**) are also present, and possibly some brachiopod shell fragments. Field of view is 5 mm.

is estimated at about 350 m on the east side of the Popelogan Anticline, taking into account the poor exposure and gradational nature of contacts. The unit is much more widely distributed on the west side of the anticline; however, folds with wavelengths of 300–600 m are common where good exposure permits their recognition and, assuming the frequency of these folds is constant throughout the northwestern part of the survey area, the thickness of the White Meadows member approximates that to the east.

The Narrows Brook member is present only on the east side of the Popelogan Anticline, where it occupies the core of an open, bowl-shaped syncline (Narrows Brook Syncline; Figure 2). The Narrows Brook member is composed of very uniform thin beds (2–6 cm) of micaceous, noncalcareous to weakly calcareous, feldspathic to arkosic siltstone and fine-grained sandstone, and minor thin beds of fine-grained calcarenite. One outcrop on a tributary of Narrows Brook consists of quartzose lithic grit containing rounded quartz clasts up to 1.2 mm, and scattered lithic clasts of fine-grained calcareous sediment. At outcrop scale, the Narrows Brook member resembles the White Meadows member in terms of bed thickness, and the presence of fossils, trace fossils, and bioturbation. Furthermore, the Narrows Brook member is petrographically similar to the White Meadows member, consisting of well-sorted, subangular to subrounded detrital grains in the silt to fine sand size-range (0.02–0.15 mm). However, the Narrows Brook member is composed dominantly of terrigenous grains, averaging 50% quartz, 30% feldspar, 1–2% muscovite, and local lithic clasts up to 2 mm in size, with only 10% clastic carbonate, and 5–10% clay matrix. Accessory zircon was noted in a number of thin sections, in contrast to its near absence in the White Meadows member. The diminished abundance of shaly beds and turbidite-related bedforms in the Narrows Brook member is consistent with shallower-water deposition compared to the White Meadows member (see also Lee and Noble 1977). Furthermore, the similar upper Llandoverian–Wenlockian range of fossil assemblages collected from each member (A.J. Boucot, in Irrinki 1990) reveals considerable overlap in their ages and also supports a shallower water vs. deeper water facies relationship. Calcareous rocks resembling the White Meadows member are locally intercalated with the Narrows Brook member, which may indicate some interfingering of the two units. The thickness of the Narrows Brook member is estimated at 700 m, based on consistent shallow dips to the north and east in a relatively well-exposed area on the west limb of the Narrows Brook Syncline, between the NBIP Road, the Indian Lake Fault, and Charlo River (Figure 2).

Age and Regional Correlation of the Upsalquitch Formation: The Upsalquitch Formation can be correlated with several other formations in northern New Brunswick and the eastern Gaspé Peninsula, including the Clemville Formation (Schuchert and Dart 1926; Bourque 1975), Weir Formation (Ayrton 1967; equivalent to the now-abandoned Armstrong Brook Formation of Noble 1976), Mann Formation (Bourque and Lachambre 1980), LaVieille Formation (Alcock 1935; Northrop 1939), and Limestone Point Formation (Noble 1976; Lee and Noble 1977; reduced to member status in the LaVieille Formation by Walker and McCutcheon 1995) (Figure 5). The Clemville Formation consists of thin-bedded shale, siltstone and minor limestone that conformably overlies the Matapédia Group, whereas the Weir Formation comprises red to green siltstone, arkosic sandstone and conglomerate that overlies the Clemville Formation. The Mann Formation conformably overlies the White Head Formation in the Ristigouche–Miguasha area in southern Gaspé Peninsula, and consists of thin-bedded, parallel- and convolute-laminated, bioturbated, fine-grained sandstone and siltstone, with minor calcilutite and calcarenite (Bourque and Lachambre 1980; Malo and Bourque 1993). The close lithological resemblance to the Upsalquitch Formation, and the areal distribution of the respective units suggests that the Mann Formation represents the continuation of the Upsalquitch Formation on the Québec side of the Restigouche River. The lithologically distinct Clemville and Weir formations, in contrast, were probably deposited in a separate paleogeographic setting to the south and east.

In the eastern part of the survey area, much of the Upsalquitch section, including parts of both the White Meadows and Narrows Brook members, have previously been assigned to the LaVieille Formation (including the Limestone Point Member, formerly Limestone Point Formation) (Irrinki 1990). However, the grey, nodular, highly fossiliferous, bioturbated limestone that typifies the LaVieille Formation is absent in the survey area, although it crops out farther northeast and southwest. The fossiliferous calcilutites and calcareous siltstones that crop out in the Arseneau Lake area (Figure 2), therefore, are included in the White Meadows member of the Upsalquitch Formation. Similarly, rocks assigned to the Limestone Point "Formation" by Irrinki (1990) are here included in the Narrows Brook member of the Upsalquitch Formation. This is consistent with the usage of Lee and Noble (1977), who included most of the Limestone Point and LaVieille formations of Irrinki (1990) in their informal "Siltstone Unit", which is equivalent to the Upsalquitch Formation. Compared to the Upsalquitch Formation, the Limestone Point rocks include a much higher proportion of limestone beds, and are characteristic of a more shallow-water environment (Noble 1976; Lee and Noble 1977). Therefore, it is proposed that the term "Limestone Point Member" be applied only to the interbedded calcareous sandstones, siltstones, and limestones that underlie the LaVieille limestone at the Limestone Point type section (Noble 1976) and in the Nash Creek area to the northeast (Irrinki 1990).

In the Popelogan Lake–Lost Pine Lake area, reported ages of fossil assemblages from rocks that are assigned here to the Upsalquitch Formation (GSC locations 91214, 91219, and 91607, Figure 2) range from Llandoverian C_3 to early Wenlockian (identifications by Boucot, in Irrinki 1990). This coincides with the Llandoverian C to early Wenlockian range reported for the LaVieille and Limestone Point formations (Ayrton 1967; Noble 1976 and references therein; Lee and Noble 1977; Nowlan 1983), and supports the view that the latter are shallow-water facies equivalents of the Upsalquitch. The lower age limit of the Upsalquitch Formation is poorly defined, the best evidence coming from correlative rocks of the Clemville and Weir formations, which locally overlie the Matapédia Group in the Gaspé Peninsula and northeastern New Brunswick. On Mictaw Brook in the Gaspé Peninsula, the Weir Formation contains lower Llandoverian (A_{3-4}) brachiopods (Ayrton 1967), whereas in the Nash Creek area in New Brunswick, as stated above, brachiopods in shale and siltstone of the Clemville Formation, immediately overlying the Matapédia Group, are Llandoverian A_{3-4} to late Llandoverian B in age. In the Upsalquitch Forks area to the south, Lee and Noble (1977) infer a Llandovery A or B age for the base of their "Siltstone Unit", based on C_1 brachiopods in the presumed middle of the unit. The Mann Formation has been assigned an early to late Llandoverian age (Bourque *et al.* 1995).

Bryant Point and Benjamin formations: Mafic and felsic volcanic rocks, respectively, of the Bryant Point and Benjamin formations (Greiner 1967), underlie the extreme southeast corner of the survey area (Figure 2). Relief is very flat and exposure almost nonexistent in this area, with only scattered subcrop having been observed; hence, the presence of these units is based on extrapolation from outcrop distribution to the northeast and southwest (Irrinki 1974, 1976). Descriptions of the volcanic rocks have been presented by several previous workers (e.g., Toong 1963; Greiner 1970; Stewart 1975; Irrinki 1990; Walker and McCutcheon 1995), and will not be repeated here. The Bryant Point Formation conformably overlies the LaVieille Formation on and near Chaleur Bay to the northeast (Walker and McCutcheon 1995). The age of the Bryant Point is limited by Llandoverian C_6 to early Wenlockian fossils in the LaVieille Formation (Boucot, in Irrinki 1990), and by a 423 ± 3 Ma (early Ludlovian) U–Pb (zircon) radiometric date obtained from the overlying Benjamin Formation (Walker *et al.* 1993).

The contact between the Upsalquitch Formation and the Bryant Point Formation in the southeast part of the survey area is interpreted as a fault. The gross structure east of Charlo River is a syncline (Narrows

Brook Syncline) and, therefore, the White Meadows member should be younger than adjacent rocks to the southeast. Instead, this area is underlain by younger rocks of the Bryant Point Formation, indicating that the two units must be juxtaposed along a fault. This conclusion is supported by regional geometrical considerations; for example, the absence of the Upsalquitch Formation on the east limb of the Benjamin River Syncline to the northeast (Walker and McCutcheon 1995), is most easily explained by a northeast-striking fault on its west limb.

INTRUSIVE ROCKS

Intrusive rocks in the Popelogan Lake–Lost Pine Lake area include Devonian felsic to intermediate plutonic rocks, i.e., the Red Brook Granodiorite (new name), and Devonian and Silurian mafic, intermediate and felsic dykes. The most significant intrusion, because of its genetic association with the Popelogan copper deposit (see below), is the Red Brook Granodiorite (Figure 2), previously known informally as the Popelogan granite. The latter name should be abandoned to avoid confusion with established nomenclature such as the Popelogan Formation and Popelogan Anticline. The Red Brook Granodiorite is a composite intrusion comprising granite, quartz monzonite, granodiorite, diorite, and porphyritic granite phases in the main stock and associated dykes, sills and apophyses. U–Pb (zircon) radiometric dating of Red Brook quartz monzonite has yielded an age of 382.7 +0.6/–2.0 Ma (V. McNicoll, personal communication), corresponding to early Late Devonian time according to the time scale of Okulitch (1999). Almost identical ages have been obtained from the Copper Mountain and Porphyry Mountain stocks at Mines Gaspé, Québec (Stephenson *et al.* 1998), and the Nicholas Denys Granodiorite near Bathurst (Walker *et al.* 1991), which is associated with the Beresford Cu–Fe skarn and Millstream Fe–Cu–Mo skarn deposits (Lentz *et al.* 1993).

Outcrops of the Red Brook Granodiorite are rare, though float and subcrop are abundant. Lithological descriptions of igneous rocks associated with the Popelogan copper deposit, based mainly on examination of drill core, have been presented by Leslie (1963). Thin sections from sparse outcrop and subcrop consist of 10–15% quartz, 25–35% alkali feldspar, 50% plagioclase, 3% biotite, and accessory apatite, zircon, ± chlorite ± monazite(?). Hence, in terms of their mineralogy, these samples are quartz monzonites. One thin section archived from an earlier mapping program (Irrinki 1974) provides evidence of a minor, previously unreported silica-undersaturated phase, and was apparently collected from a dyke (no longer exposed) on the NBIP Road southwest of the Popelogan deposit (Figure 3). This sample can be described as a nepheline monzonite porphyry, and contains 15% nepheline, 5% alkali feldspar, 70% plagioclase, chlorite, calcite and muscovite as alteration products, very abundant apatite (~2%), and accessory zircon, titanite, and opaque minerals.

Devonian mafic plutonic rocks are represented by scattered coarse-grained dykes (?) near the Popelogan deposit, and by an intrusion of unknown dimension (exposed in a single outcrop) in the eastern part of the survey area east of Narrows Brook (Figure 2). These rocks are dioritic in composition and consist of 50–55% plagioclase (andesine), up to 25% pyroxene (altered to epidote or chlorite), ± calcite, ± minor quartz, ± actinolite, and accessory titanite and opaque minerals.

Felsic dykes and sills are numerous and widespread, and generally fall into one of two groups: (1) pink to pinkish orange, aphyric to locally sparsely feldspar-phyric, spherulitic to granophyric felsite or microgranite; and (2) pinkish orange to red, maroon, or buff feldspar porphyry, feldspar–biotite porphyry, or (rarely) feldspar–quartz porphyry containing alkali feldspars from 2 mm to 1 cm. Group 1 dykes and sills are found only to the east of Charlo River, and are particularly abundant between Charlo River and Narrows

Brook. Three larger bodies (unit Sfi, Figure 2), near Arseneau Lake, are probably thick sills that assume the dimensions of plutonic masses because of the shallow dips of the enclosing strata. Due to the paucity of outcrop in this area, interpreted contacts are approximate at best. The fine grain size and spherulitic/ granophyric textures of these rocks indicate high-level intrusion and rapid chilling, consistent with emplacement as narrow tabular bodies rather than stocks or plugs. Group 2 dykes and sills are located mainly in the core and west limb of the Popelogan Anticline; they are especially numerous in the upper part of Goulette Brook and along Belanger Road in the southwestern part of the survey area (Figure 2). As discussed below (see Geochemistry), group 1 intrusions are interpreted to be Late Silurian to earliest Devonian, and group 2 Middle Devonian, because of their close chemical similarities to plutonic rocks of those respective ages elsewhere in northern New Brunswick and Gaspé (Whalen 1993; Whalen *et al.* 1994).

Dark green, fine-grained mafic dykes and sills are also widespread, particularly in the northern part of the survey area, and intrude all units; however, no chemical analyses have been carried out on these rocks, and their age is unknown.

GEOCHEMISTRY

Representative samples of sedimentary and mafic and felsic igneous rocks were collected for whole-rock analysis, and the data combined with previously published and unpublished analyses of rocks from the survey area. The combined data include: (1) 12 analyses of mafic volcanic rock from the Goulette Brook Formation (Table 1), including 4 analyses of newly collected samples and 8 analyses of basalts and tuffs from a drill hole near Goulette Brook (previously reported by Irrinki 1990); (2) 28 analyses of felsic intrusive rocks (Table 2), including 9 new analyses, 11 analyses from Giggie (1999) (KVG-8, 34, 36, 39, 42, 45, 56, 58, 59, 96, and 98), and unpublished data from 8 samples collected by G. Philpott (GP-1109, 2031, 2063A, 2083, 2084, 2085, 2087, and 2089; see Philpott 1990a, 1990b for sample locations); and (3) 22 newly collected samples of sedimentary rocks (Table 3). As may be expected with samples collected by different workers over a number of years, different laboratories were used and detection limits for some elements varied. However, in most cases the same analytical method was used for any given element (see below), and analytical accuracy and precision, where evaluation was possible, were within acceptable limits. Most importantly, repeat sampling of the same rock unit returned similar values for major oxides and trace-elements; hence, the data are considered useful for inter-unit comparison.

Mafic volcanic rocks

Mafic volcanic rocks of the Goulette Brook Formation have been divided into three groups based on chemical and lithological characteristics (Table 1). Group I samples (four massive basalts from the core of the Popelogan Anticline) were analyzed at X-Ray Assay Laboratories by X-ray fluorescence spectrometry (XRF) (major oxides, Ba, Rb, Sr, Nb, Y, and Zr), by multi-acid digestion and inductively-coupled plasma emission spectroscopy (ICP) (Ni, V, Cu, Pb and Zn), and by instrumental neutron activation analysis (INAA) for Cr, Co, Sc, Hf, Ta, Th, U and rare-earth elements (REEs). Groups II and III (three lapilli tuffs and five amygdaloidal basalts, respectively, from drill core that intersected the upper part of the Goulette Brook Formation—see above) were analyzed at St. Mary's University by XRF (major oxides, Cr, Ni, V, Cu, Zn, Ga, Ba, Rb, Sr, Y, Zr and Nb) and INAA (all REEs). Unfortunately, a full suite of trace-elements is unavailable for groups II and III. Sample preparation for group I basalts was by agate milling; however, preparation methods are unknown for groups II and III.

Table 1. Geochemistry of Mafic Volcanic Rocks of the Goulette Brook Formation

	Group I Lavas (n=4)			Group II Tuffs (n=3)			Group III Lavas (n=5)		
	Avg.	Anhyd.	SD	Avg.	Anhyd.	SD	Avg.	Anhyd.	SD
(wt%)									
SiO_2	51.35	53.79	1.91	40.05	47.78	3.98	50.65	52.94	1.51
TiO_2	1.04	1.09	0.27	0.45	0.54	0.09	1.16	1.21	0.06
Al_2O_3	14.65	15.35	0.70	6.49	7.74	1.47	19.72	20.61	0.65
Fe_2O_3	11.55	12.10	0.90	10.20	12.17	0.34	12.51	13.08	2.22
MnO	0.15	0.15	0.06	0.18	0.21	0.03	0.30	0.31	0.06
MgO	5.69	5.96	2.35	14.96	17.85	4.76	2.56	2.67	0.16
CaO	5.73	6.00	2.47	10.95	13.06	1.23	1.27	1.33	0.36
Na_2O	4.30	4.51	0.65	0.23	0.27	0.17	3.85	4.02	0.46
K_2O	0.84	0.88	0.56	0.17	0.20	0.27	3.23	3.38	0.94
P_2O_5	0.16	0.17	0.04	0.14	0.17	0.04	0.42	0.44	0.04
LOI	4.19		1.62	17.50		3.70	4.22		0.54
(ppm)									
Cr	74		108	1898		175	9		5
Co	35.0		9.2						
Ni	30.3		34.5	583.0		86.6	22.2		3.6
Sc	36.8		2.8						
V	332.0		49.4	227.7		53.4	54.6		8.0
Cu	69.3		36.0	53.7		10.0	20.6		7.9
Pb	1.0		0.0				19.2		11.7
Zn	100.0		15.7	67.0		5.6	130.8		17.3
Ga				8.7		1.2	23.0		2.3
Ba	238		139	104		44	1585		217
Rb	22		7	8			43		18
Sr	209		21	331		173	92		14
Y	20.8		4.0	9.3		2.1	42.4		5.2
Zr	86		28	39		4	214		17
Hf	2.6		1.0						
Nb	5.3		3.0	3.3		0.6	12.2		0.8
Ta	2.3		0.5						
Th	4.8		2.1				12.2		4.1
U	1.2		0.8						
La	17.48		7.19	16.50		15.41	62.95		4.45
Ce	28.75		15.63	39.40		38.47	133.00		11.31
Pr				5.55		5.59	16.45		0.92
Nd	17.00		4.69	26.90		27.29	70.50		0.14
Sm	4.15		1.31	6.10		6.51	13.10		0.28
Eu	1.30		0.27	1.81		1.70	3.45		0.22
Gd				6.55		7.00	11.00		0.42
Tb	0.66		0.31	1.05		1.06	1.55		0.07
Dy				5.55		5.87	8.05		0.07
Ho				1.07		1.11	1.54		0.01
Er				3.05		3.04	4.15		0.07
Tm				0.50		0.42	0.60		0.00
Yb	2.33		0.62	2.80		2.97	3.50		0.14
Lu	0.26		0.08	0.47		0.44	0.55		0.00

Notes: **anhyd.**—major oxides recalculated to 100% (anhydrous); **SD**—standard deviation.

Table 2. Geochemistry of Intrusive Rocks, Popelogan Lake–Lost Pine Lake area.

	Sfi (n=11)		Dii (n=5)		DRDii (n=10)		Dmi (n=2)	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
(wt%)								
SiO_2	75.54	1.56	66.04	1.31	65.60	2.14	52.54	2.88
TiO_2	0.12	0.05	0.46	0.12	0.58	0.08	1.47	0.62
Al_2O_3	12.75	0.97	15.72	0.65	16.13	0.47	17.75	1.06
Fe_2O_3	1.35	0.43	2.96	0.62	3.49	0.69	8.55	1.27
MnO	0.02	0.01	0.04	0.01	0.04	0.02	0.28	0.16
MgO	0.14	0.06	1.32	0.35	1.62	0.26	4.80	1.31
CaO	0.32	0.43	2.50	0.88	2.99	1.06	4.24	2.96
Na_2O	3.30	1.07	5.16	1.31	4.64	0.64	3.17	3.15
K_2O	4.36	1.32	1.90	0.83	2.30	0.50	2.86	3.29
P_2O_5	0.02	0.02	0.11	0.03	0.16	0.03	0.24	0.10
LOI	1.25	0.58	3.62	1.49	1.66	0.87	4.00	1.41
(ppm)								
Cr	23	14	16	5	28	11	76	72
Co	1.8	1.0	10.4	3.6	9.0	3.0	27.0	8.0
Ni	2.2	0.6	6.0	3.4	15.0	7.0	36.0	42.0
Sc	4.1	3.0	6.2	2.0	7.6	1.6	32.8	5.7
V	5.8	5.9	43.8	13.9	66.0	14.7	263.0	33.0
Cu	3.1	1.1	4.2	3.4	63.4	135.4	64.7	52.8
Pb	17.1	9.5	1.0	0.0	10.0	6.9	3.5	3.5
Zn	46.2	20.7	45.7	15.9	60.0	28.3	308.8	303.0
Ag	0.3	0.2	0.1	0.1	0.3	0.1	0.4	0.1
As	11.0	20.0	1.6	1.3	1.5	1.0	1.0	0.0
Sb	3.0	3.2	0.5	0.5	1.1	1.1	1.8	1.1
Sn	5.4	1.9	5.0	0.0	2.0	2.0	3.5	2.1
W	1.6	0.8	1.5	0.0	1.9	2.6	1.0	0.7
Mo	1.4	0.5	0.5	0.0	3.9	8.5	0.8	0.4
Au(ppb)	2.0	1.2	2.5	0.0	3.3	3.0	1.8	1.1
Ga	21.8	2.7			20.6	0.6	18.8	0.0
Ba	409	297	357	211	683	338	755	773
Rb	154	65	53	27	67	16	84	88
Sr	71	44	325	120	784	314	416	178
Y	50.0	19.2	9.6	3.3	11.9	6.1	21.0	1.4
Zr	161	96	141	21	137	20	114	44
Hf	5.5	2.2	3.6	0.4	3.7	0.5	3.4	1.1
Nb	19.5	8.7	8.6	2.1	8.7	3.3	9.0	2.8
Ta	1.7	1.0	2.4	1.5	0.9	0.5	2.6	3.4
Th	20.4	6.2	6.7	1.1	7.9	1.6	4.1	0.7
U	5.7	2.1	1.7	0.4	2.0	0.8	1.1	0.2
La	25.95	15.84	23.80	4.27	30.88	10.71	24.90	7.21
Ce	73.27	30.06	44.60	6.58	49.80	12.41	48.50	7.78
Nd	21.45	8.58	17.60	2.70	19.00	4.99	23.00	0.00
Sm	5.27	2.54	3.04	0.46	3.64	0.89	4.91	0.70
Eu	0.47	0.36	0.96	0.17	1.22	0.32	1.94	0.20
Tb	1.20	0.44	0.39	0.19	0.40	0.13	1.00	0.42
Yb	4.85	1.55	0.92	0.26	1.02	0.21	2.25	0.22
Lu	0.71	0.23	0.10	0.04	0.18	0.06	0.28	0.02

Notes: **Sfi**—Late Silurian to earliest Devonian (?) felsic dykes and sills; **Dii**—Middle Devonian (?) intermediate dikes and sills; **DRDii**—Middle Devonian Red Brook Granodiorite; **Dmi**—Middle Devonian mafic intrusive rocks; **SD**—standard deviation.

Table 3. Geochemistry of Sedimentary Rocks, Popelogan Lake–Lost Pine Lake Area.

	UPnb (n=3)			UPwm (n=9)			UPpcl (n=4)		WH (n=6)		
	Avg.	Anhyd.	SD	Avg.	Anhyd.	SD	Avg.	SD	Avg.	Anhyd.	SD
(wt%)											
SiO_2	67.53	70.23	3.33	48.64	56.53	9.48	56.38	2.97	22.02	31.08	4.51
TiO_2	0.61	0.64	0.12	0.52	0.60	0.15	0.68	0.16	0.30	0.42	0.06
Al_2O_3	13.27	13.80	1.32	10.01	11.63	2.18	15.13	1.51	5.75	8.11	1.29
Fe_2O_3	4.29	4.46	1.40	4.07	4.74	0.93	5.21	1.76	2.61	3.68	0.49
MnO	0.05	0.05	0.01	0.10	0.11	0.02	0.12	0.03	0.08	0.11	0.07
MgO	2.55	2.65	1.00	2.65	3.10	0.43	3.43	1.29	2.34	3.30	0.83
CaO	2.05	2.13	0.52	15.97	19.27	6.96	12.40	6.08	35.27	50.42	3.77
Na_2O	3.45	3.58	0.46	1.66	1.92	0.58	1.97	1.35	0.55	0.77	0.23
K_2O	2.31	2.40	0.28	1.68	1.97	0.52	2.37	1.54	1.41	1.97	0.55
P_2O_5	0.09	0.10	0.03	0.09	0.10	0.02	0.11	0.02	0.05	0.07	0.01
LOI	2.88		0.53	14.68		5.62	1.70	1.30	29.42		3.64
(ppm)											
Cr	199		9	130		38	193	43	61		13
Co	16.0		6.1	16.2		4.8	21.3	8.5	8.3		1.9
Ni	65.7		37.1	61.2		21.5	84.5	32.9	34.5		9.6
Sc	13.2		3.7	10.6		2.9	17.1	5.4	6.8		1.6
V	78.3		24.0	62.9		20.1	101.5	19.7	43.5		9.7
Cu	13.1		9.3	13.9		6.8	30.4	36.2	9.6		2.6
Pb	2.3		2.3	4.3		1.9	33.0	37.8	2.8		2.8
Zn	58.6		17.3	57.5		17.4	91.8	54.8	39.8		12.0
As	3.3		2.1	3.4		0.7	3.3	2.2	2.5		1.0
Sb	0.2		0.2	0.2		0.1	0.9	0.5	0.1		0.0
Au(ppb)	2.5		0.0	2.5		0.0	2.5	0.0	3.8		3.1
Cs	2.5		2.3	2.9		1.2	2.5	2.6	2.0		0.6
Ba	503		88	934		1873	396	283	268		103
Rb	82		17	74		19	89	57	67		22
Sr	329		55	582		278	289	114	854		187
Y	19.7		1.2	19.6		4.8	26.8	4.3	8.3		2.2
Zr	220		22	112		58	120	47	44		8
Hf	5.7		0.5	3.3		1.5	4.1	0.7	1.6		0.3
Nb	11.7		2.1	7.1		3.1	9.3	3.0	2.0		0.9
Ta	1.7		0.6	1.2		0.8	1.6	0.8	0.5		0.0
Th	7.9		1.8	6.1		2.1	8.9	2.3	3.7		0.9
U	1.8		0.3	1.3		0.5	1.9	0.5	1.0		0.2
La	33.00		2.00	23.78		6.06	36.50	4.20	14.33		2.16
Ce	66.67		4.62	51.44		13.05	74.00	7.07	30.00		3.41
Nd	29.67		1.53	22.67		3.81	31.00	2.16	14.33		1.03
Sm	5.47		0.42	4.50		0.97	6.13	0.15	2.55		0.23
Eu	1.40		0.10	1.06		0.22	1.40	0.08	0.58		0.08
Tb	0.70		0.26	0.67		0.15	0.88	0.10	0.29		0.10
Yb	2.10		0.36	1.79		0.39	2.45	0.19	1.00		0.13
Lu	0.26		0.04	0.22		0.05	0.31	0.02	0.13		0.02

Notes: **UPnb**, **UPwm**, **UPpcl**—Upsalquitch Fm. (Narrows Brook member, White Meadows member, porcellanite); **WH**—White Head Formation (Matapedia Group); **anhyd.**—major oxides recalculated to 100% (anhydrous); **SD**—standard deviation.

Group I massive lavas and group II lapilli tuffs plot in the subalkaline basalt and andesitic basalt fields on a Nb/Y vs. Zr/TiO_2 diagram (Figure 8a), whereas group III amygdaloidal lavas (the upper part of the Goulette Brook Formation) plot in the andesite field because of their elevated abundance of Zr (Table 1). All basalts fall in the arc volcanic field on a Nb–Zr–Y ternary discrimination diagram (Figure 8b), and show prominent negative Nb and Ti anomalies and Rb, Ba and LREE (light REE) enrichment (Figure 8c) typical of subduction-related basalts. However, Sr does not exhibit any of the expected enrichment and, in fact, group III is greatly depleted in Sr (Figure 8c). Furthermore, groups I and III display enrichment in Th that is not typical of oceanic arcs, and implies some continental influence. Each group is characterized by distinctive chemical signatures, suggesting a complex petrogenesis for the unit as a whole. Group III basalts contain significantly higher abundances of Al_2O_3, K_2O, P_2O_5, HFSEs (high field-strength elements, such as Nb, Y, Zr, Th), Ba and REEs compared to Group I basalts, reflecting their more evolved, "andesitic" composition, although their SiO_2 values are similar and within the basaltic range (Table 1). Group I basalts, in contrast, contain more MgO, CaO, Cr, Ni, V, Cu and Sr. Group II lapilli tuffs have very "primitive" Mg-rich compositions, and were referred to as "ultramafic hyaloclastites" by Philpott (1988); however, they show very high loss-on-ignition (average 17.5%) because of their abundant secondary carbonate, and an anhydrous normalization of major oxide abundances reveals that SiO_2 falls within the normal range of basalts (Table 1). All three basalt types display subparallel, sloping REE profiles (La_N/Yb_N = 4.2 to 12.9) with no Eu anomaly (Figure 8d); the steepest slope and greatest LREE enrichment is present in the andesitic Group III basalts.

Group II tuffs resemble picritic basalts in most respects (e.g., Nye and Reid 1986; Eggins 1993), such as low to very low TiO_2, Al_2O_3, Na_2O, K_2O and HFSEs, and very high contents of Cr and Ni; the Mg# (= mol. MgO x 100/[mol. MgO + 0.87 mol. FeO_T]) varies from 70 to 82. These compositions have been interpreted as evidence that picrites represent analogues of primary mantle-equilibrated magmas (e.g., Francis 1995). However, compared to typical picrites, at least one of the Popelogan samples is significantly enriched in REEs. The average REE values for Group II tuffs (Table 1) are calculated from only two samples, containing low (ΣREE = 34.7 ppm, normal for picritic basalts) and moderate (ΣREE = 199.9 ppm) REE abundances, respectively. Both samples display LREE enrichment (La_N/Sm_N = 1.7–2.4), which is common in arc picrites (e.g., Eggins 1993; Ramsay *et al.* 1984), and HREE (heavy REE) depletion (Gd_N/Yb_N = 1.9–2.5). REEs are relatively enriched compared to HFSEs (Ti, Nb, Y and Zr), and group II tuffs consequently display a rather jagged profile on a trace-element spiderplot (Figure 8c). Low abundances of HFSEs and HREEs may be related to the presence of HFSE/HREE-bearing accessory minerals in the region of melt production, or to high degrees of partial melting. Enrichment in LREEs, Rb, Ba, and possibly Th, on the other hand, may indicate addition of these elements to the mantle before melting, probably derived by dehydration or partial melting of subducted oceanic crust. However, more analytical data are needed for these rocks before their petrogenesis can be confidently interpreted. Furthermore, the high levels of secondary carbonate probably has some impact on trace-element systematics, and it is recommended that, if analysis of these tuffs is considered in the future, the samples should be crushed and sorted to remove as much carbonate matrix as possible.

Intrusive rocks

Intrusive rocks have been divided into four groups (Table 2), namely, intermediate plutonic rocks of the Middle to earliest Late Devonian Red Brook Granodiorite (10 samples), mafic phases associated with the Red Brook Granodiorite (2 samples), and two populations of felsic dykes/sills, characterized by contrasting lithology and chemistry. One type, consisting mainly of microgranites, is tentatively identified as Late Silurian (11 samples), and the other, primarily comprising feldspar porphyry, as Middle Devonian

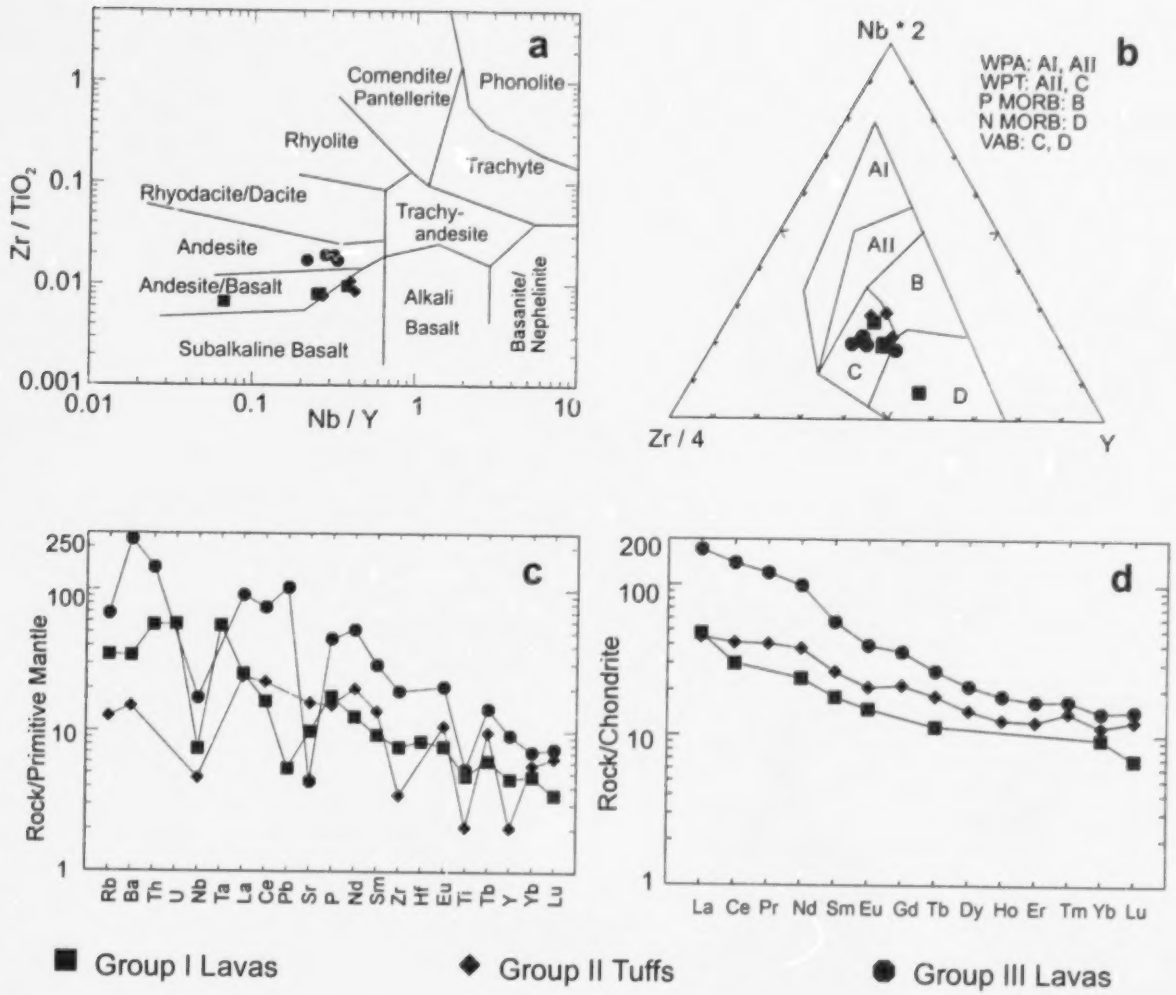


Figure 8. Trace-element variation diagrams for mafic volcanic rocks of the Goulette Brook Formation. (a) Nb/Y vs. Zr/TiO_2 diagram (Winchester and Floyd 1977); (b) Nb–Zr–Y discrimination diagram of Meschede (1986). **WPA**—within-plate alkalic basalt; **WPT**—within-plate tholeiitic basalt; **N MORB**—normal mid-ocean-ridge basalt; **P MORB**—plume-influenced mid-ocean-ridge basalt; **VAB**—volcanic-arc basalt; (c) primitive mantle-normalized trace-element spidergram, using average compositions of each basalt type; normalizing factors are from Sun and McDonough (1989); (d) average chondrite-normalized REE profiles; normalizing factors are from Sun (1982).

(5 samples). Major oxides, Ba, Rb, Sr, Nb, Y, Zr and Ga were analyzed by XRF spectroscopy at the University of Ottawa and at X-ray Assay Laboratories; Ni, V, Cu, Pb, Zn, Ag, Sn and Mo were determined by double-coupled plasma emission spectroscopy (DCP) or by multi-acid digestion and ICP at Acme Analytical Laboratories and X-Ray Assay Laboratories; and Cr, Co, Sc, As, Sb, W, Au, Hf, Ta, Th, U and REEs were analyzed by INAA at Activation Laboratories and X-Ray Assay Laboratories. Samples collected by Giggie (1999) were pulverized using a chrome steel mill, whereas those collected by this writer were prepared by agate milling; the preparation method for samples from Philpott (1987, 1988) is unknown.

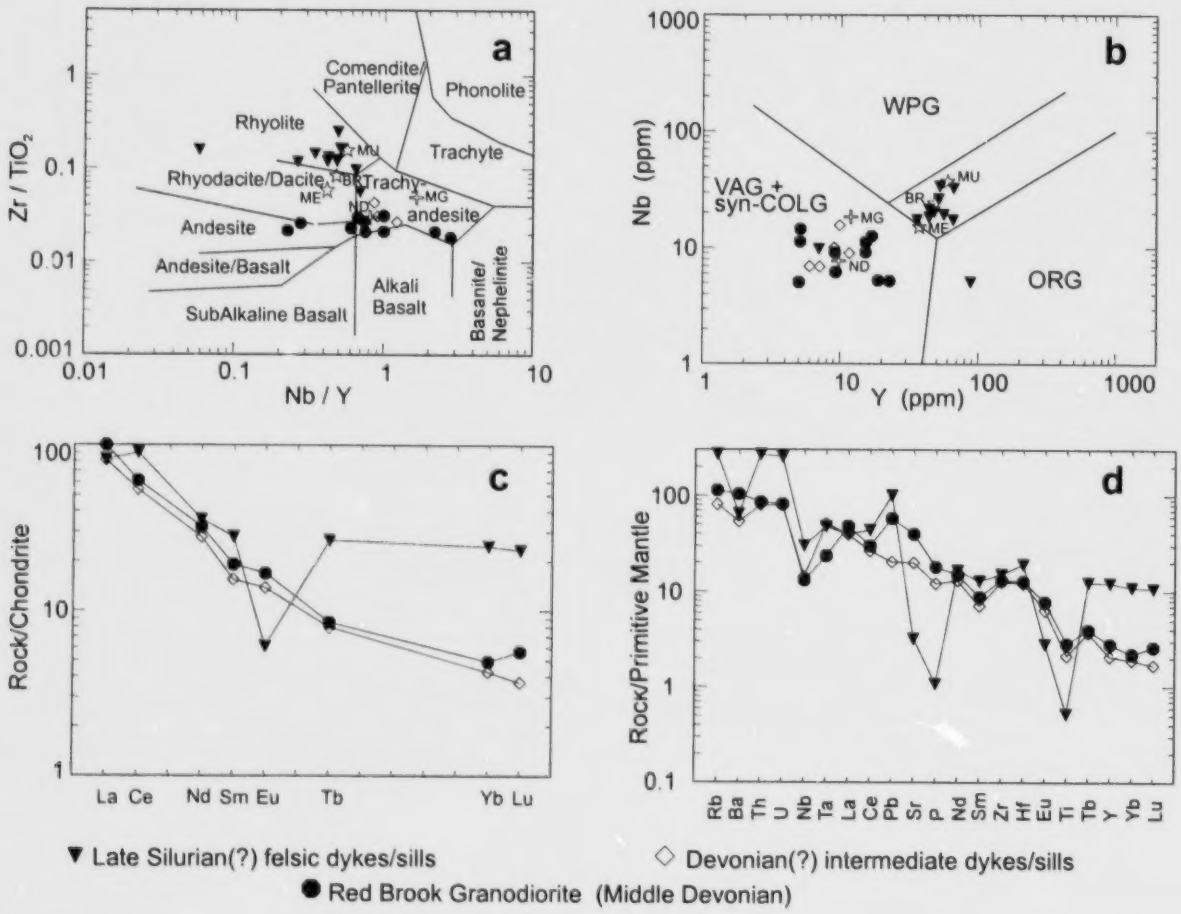


Figure 9. Trace-element variation diagrams for intermediate to felsic intrusive rocks in the Popelogan Lake–Lost Pine Lake area. (a) Nb/Y vs. Zr/TiO_2 diagram (Winchester and Floyd 1977); (b) Y vs. Nb tectonic discrimination diagram for granites (Pearce *et al.* 1984); **WPG**—within-plate granite; **VAG + syn-COLG**—volcanic arc and syn-collision granites; **ORG**—ocean-ridge granite; (c) average chondrite-normalized REE profiles; normalizing factors are from Sun (1982); (d) primitive mantle-normalized trace-element spidergram, using average composition of each type of intrusion; normalizing factors are from Sun and McDonough (1989). Average compositions of other plutonic rocks from northern New Brunswick and Gaspé (from Whalen 1993; Whalen *et al.* 1994) are plotted on (a) and (b) for comparison (☆—Silurian intrusions; ✣—Devonian intrusions); **ND**—Nicholas Denys Granodiorite; **MG**—Mines Gaspé porphyries; **ME**—Mount Elizabeth Granite; **BR**—granite from the Benjamin River complex; **MU**—Mulligan Gulch Porphyry.

Microgranite dykes/sills have felsic, subalkaline compositions (Nb/Y < 0.6), and plot in the rhyolite field on a Nb/Y vs. Zr/TiO_2 diagram (Figure 9a), whereas feldspar porphyry dykes/sills and the Red Brook Granodiorite are dominantly alkaline (Nb/Y > 0.6), have intermediate compositions (an average of 10% less SiO_2 than the microgranites; Table 2), and mainly fall in the trachyandesite field on a Nb/Y vs. Zr/TiO_2 diagram (Figure 9a). The intermediate rocks resemble volcanic-arc granites because of their low abundances of Nb and Y, unlike the microgranites, which have significantly higher contents of HFSE such as Zr, Hf, Y, Nb, Ti and Th (Table 2) and, therefore, plot as within-plate granites (Figure 9b). In addition, the microgranites contain lower Fe_2O_3, MgO, CaO, Na_2O, P_2O_5, Co, Sc, V and Sr, and higher

K_2O, Rb and U (Table 2). The abundance of LREEs is similar in all groups, but the microgranites contain much higher levels of HREEs (hence flatter REE profiles) and a prominent negative Eu anomaly not seen in the intermediate rocks (Figure 9c). Trace-element systematics of the respective groups are summarized in a spidergram (Figure 9d), which illustrates the close chemical similarity between the feldspar porphyry dykes and the Red Brook Granodiorite, except for slightly elevated Pb and Sr in the latter. In contrast, the microgranites show relative enrichment in Rb, Nb, Th, U, Pb and HREEs, and strong depletion in Sr, P, Eu and Ti.

In the absence of independent confirmation such as radiometric dating, lithogeochemistry is used to provisionally assign a Late Silurian to earliest Devonian age to the microgranites, and a Middle Devonian age to the feldspar porphyries. The microgranites and feldspar porphyries are chemically similar to intrusive rocks of Late Silurian–Early Devonian and Middle Devonian age, respectively, in northern New Brunswick and Gaspé (Whalen 1993; Whalen *et al.* 1994) (Figure 9a, b). For example, the Nicholas Denys Granite near Bathurst (381 ± 4 Ma; Walker *et al.* 1991) and the Porphyry Mountain stock (384.9 ± 2.5 Ma; Stephenson *et al.* 1998) at Mines Gaspé (in addition to the Red Brook Granodiorite) chemically resemble the feldspar porphyries, whereas the microgranites resemble Late Silurian–Early Devonian plutons such as the Mount Elizabeth Granite (417 ± 2 Ma; Bevier and Whalen 1990), the quartz monzonite phase of the Benjamin River complex (418 ± 1 Ma; Walker *et al.* 1991) and the Mulligan Gulch Porphyry (419 ± 1 Ma; McCutcheon and Bevier 1990) (Figure 9a, b).

Sedimentary rocks

Whole-rock analysis was carried out on 6 samples of calcilutite from the White Head Formation (Matapédia Group), and 16 samples from the Upsalquitch Formation, including 3 samples of noncalcareous siltstone or fine-grained sandstone from the Narrows Brook member, 9 samples of calcarenite and calcilutite/ calcareous siltstone from the White Meadows and Arsenault Brook members, and 4 samples displaying calc-silicate alteration (porcellanite). Three samples from the Arsenault Brook member are included with the White Meadows suite (Table 3, Figure 10) because the chemical differences between them are negligible. All analyses were carried out at X-Ray Assay Laboratories by XRF spectroscopy (major oxides, Ba, Rb, Sr, Nb, Y and Zr), multi-acid digestion and ICP (Ni, V, Cu, Pb and Zn), and INAA (Cr, Co, Sc, As, Sb, Au, Cs, Ta, Hf, Th, U and REEs). All samples were prepared by agate milling.

Much of the variation in the major oxide-element and trace-element abundances in the Upsalquitch and White Head formations can be explained by differences in carbonate content and consequent "dilution" of terrestrial components. For example, the Narrows Brook member, White Meadows member and White Head Formation, containing 2%, 19% and 50% CaO (anhydrous), respectively, show corresponding progressive decreases in major oxides (except for MgO, MnO and P_2O_5), compatible elements (Cr, Ni, Sc and V), HFSEs (Y, Zr, Hf, Nb, Ta, Th and U), and REEs. An opposite trend is seen in Sr, because of its geochemical affiliation with Ca, whereas some other elements show no consistent pattern. Linear (constant ratio) relationships involving several trace-elements are illustrated on Zr vs. Y, Zr vs. TiO_2, and Sc vs. Th variation diagrams (Figures 10a, b and c); similar constant-ratio relationships exist among many other trace-elements, e.g., Cr, Co, Ni, Sc and V. The Narrows Brook member displays some enrichment in Zr, as shown by the departure from a linear trend on the Zr vs. Y and Zr vs. TiO_2 diagrams (Figures 10a, b). This enrichment implies an increased input from continental crust, and is reflected in the presence of detrital zircons in thin sections of Narrows Brook sandstones. However, the Th/Sc ratio, which is a sensitive indicator of average provenance composition (McLennan *et al.* 1990), is more consistent with an arc-related setting. For example, upper continental crust is characterized by Th/Sc ratios of approximately 1.0, whereas values below 1.0 indicate an increased mafic component as may be expected

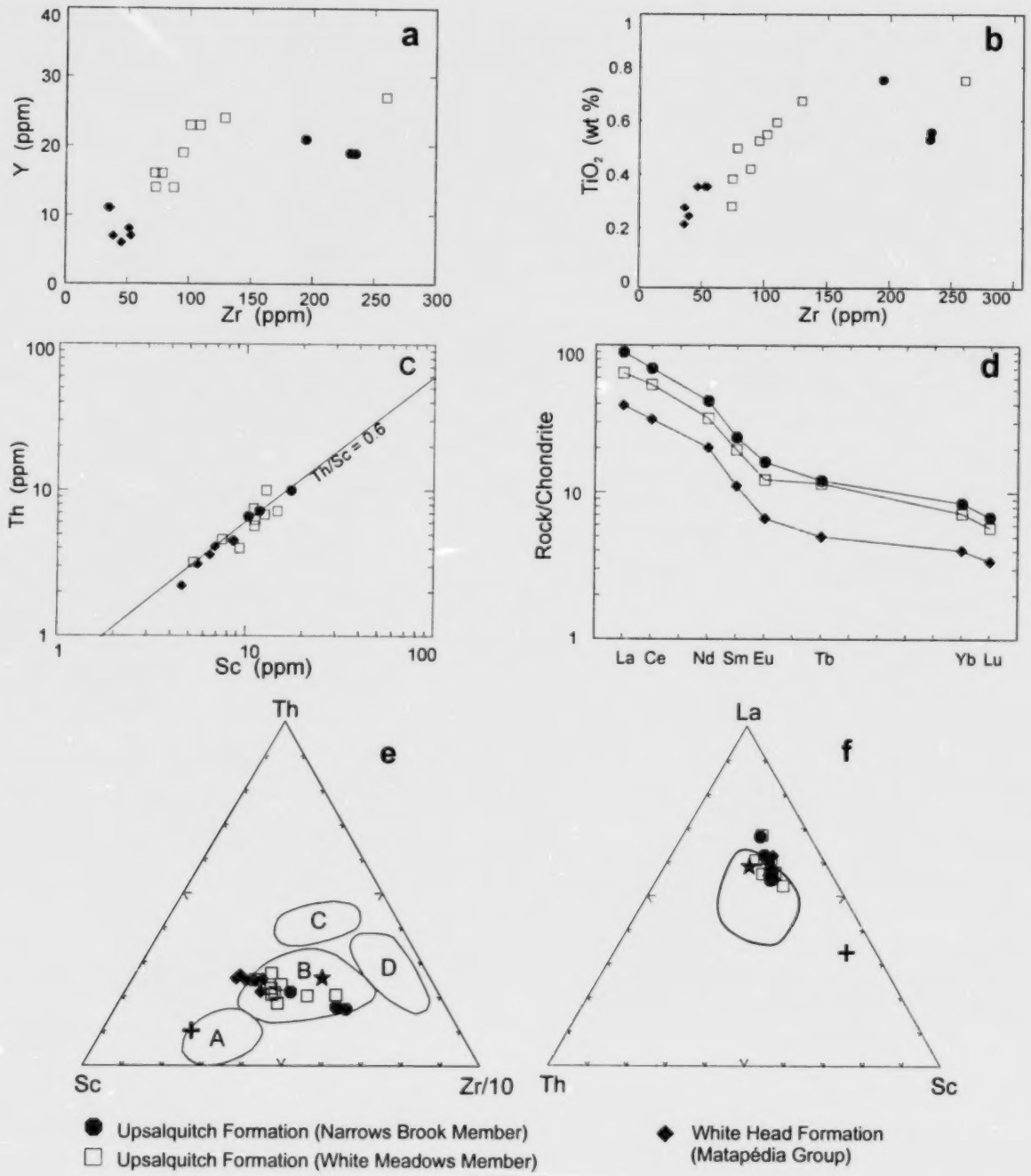


Figure 10. Trace-element variation diagrams for sedimentary rocks in the Popelogan Lake–Lost Pine Lake area. (a) (b) and (c) bivariate plots: Zr vs. Y, Zr vs. TiO_2, and Sc vs. Th, respectively; (d) average chondrite-normalized REE profiles; normalizing factors are from Sun (1982); (e) Sc–Th–Zr tectonic discrimination diagram for sedimentary rocks (Bhatia and Crook 1986); empirically derived tectonic settings are as follows: **A**—oceanic island arc, **B**—continental island arc, **C**—active continental margin, **D**—passive margins; (f) Th–La–Sc discrimination diagram for sedimentary rocks (Bhatia and Crook 1986); solid line outlines field of sedimentary rocks deposited in continental island arc settings. ★ and + in (e) and (f) represent average compositions of upper (continental) crust and island arc andesites, respectively, from Taylor and McLennan (1985).

in convergent margin settings (Taylor and McLennan 1985). The Th/Sc ratio of the Upsalquitch Formation is consistently around 0.6, whereas the ratio in the White Head Formation is slightly less at 0.55 (Figure 10c); these ratios imply considerable input from immature volcanic terranes. Similarly, average La/Th in the survey area ranges from 3.9 to 4.2, close to the values for continental island-arc rocks (~4.5; Bhatia and Taylor 1981) with some influence from upper continental crustal sources (average La/Th ~2.7; McLennan *et al.* 1990). In contrast, average Th/U for the White Head Formation, and White Meadows and Narrows Brook members of the Upsalquitch Formation are 3.7, 4.7 and 4.4, respectively (Table 3), much higher than normal for sedimentary rocks in convergent-plate settings (~2.5–3.0; Bhatia and Taylor 1981), and at or above the average upper-crustal value of 3.8 (McLennan *et al.* 1990). Elevated Th/U may be related to oxidation and removal of U during weathering and sedimentation (see McLennan and Taylor 1980).

Rare-earth-element data from the study area present ambiguous evidence concerning the nature of the source rocks for the Upsalquitch and White Head formations. REE profiles (Figure 10d) show strong LREE enrichment and flatter slopes for the middle and heavy REEs; average La_N/Sm_N ranges from 3.4 to 3.9, and average La_N/Yb_N from 9.5 to 11.3, with the highest values occurring in the Narrows Brook member. These patterns are most similar to those of some passive-margin sedimentary rocks (McLennan *et al.* 1990). Similarly, the absence of a negative Eu anomaly, except for a slight anomaly in the Narrows Brook member, is a feature that is not normally found in arc, back-arc or fore-arc settings, but is more common in some passive-margin and continental-collision basins (McLennan *et al.* 1990). However, Bhatia (1985) describes a chemically diverse suite of continental island-arc sedimentary rocks that commonly display LREE enrichment (average $La_N/Sm_N = 3.1$, $La_N/Yb_N = 7.3$) and no Eu anomaly. The higher La_N/Sm_N and La_N/Yb_N in sedimentary rocks from the study area, particularly in the Narrows Brook member, confirms at least some input from granitic or sedimentary continental crustal sources. Increasing LREE/HREE ratios and total REE abundances have been associated with changes in dominant source rocks from andesite to dacite to granite-gneiss to sedimentary rocks (Bhatia 1985), roughly corresponding to fields A through D, respectively, on the Sc–Th–Zr discrimination diagram (Figure 10e).

Ternary trace-element diagrams offer useful inter-unit comparisons because such diagrams are unaffected by dilution related to high carbonate contents. On the Sc–Th–Zr and Th–La–Sc diagrams of Bhatia and Crook (1986) (Figures 10e, f), sedimentary rocks in the study area are clustered near the composition of average upper crust (Taylor and McLennan 1985), and most plot within the field of continental island-arc basins, consistent with other trace-element and REE data described above. Th, La and Zr values are considerably higher than those associated with average island-arc andesites (Taylor and McLennan 1985) (Figures 10e, f). It is clear on the Sc–Th–Zr diagram that the younging-upward sequence of White Head Formation, White Meadows member and Narrows Brook member records a transition from sediments reflecting the influence of arc volcanism, toward more "mature", passive-margin-type compositions (Figure 10e). Major-oxide abundances and ratios in the Upsalquitch and White Head formations are also similar to typical values for continental island-arc basins, especially the former, e.g., $Fe_2O_3 + MgO = 7–8\%$, $TiO_2 = \sim 0.6\%$, $Al_2O_3/SiO_2 = 0.2$, and $K_2O/Na_2O = 0.7–1.0$ (Bhatia 1983). In summary, it appears that most of the evidence supports a continental island-arc-related provenance for the sedimentary rocks, with increasing input from continental sources over time.

STRUCTURAL GEOLOGY

The major structural feature in the survey area is the Popelogan Anticline (Figure 2), which strikes north-northeast and plunges to the north based on changes in bedding attitudes in the Upsalquitch and White

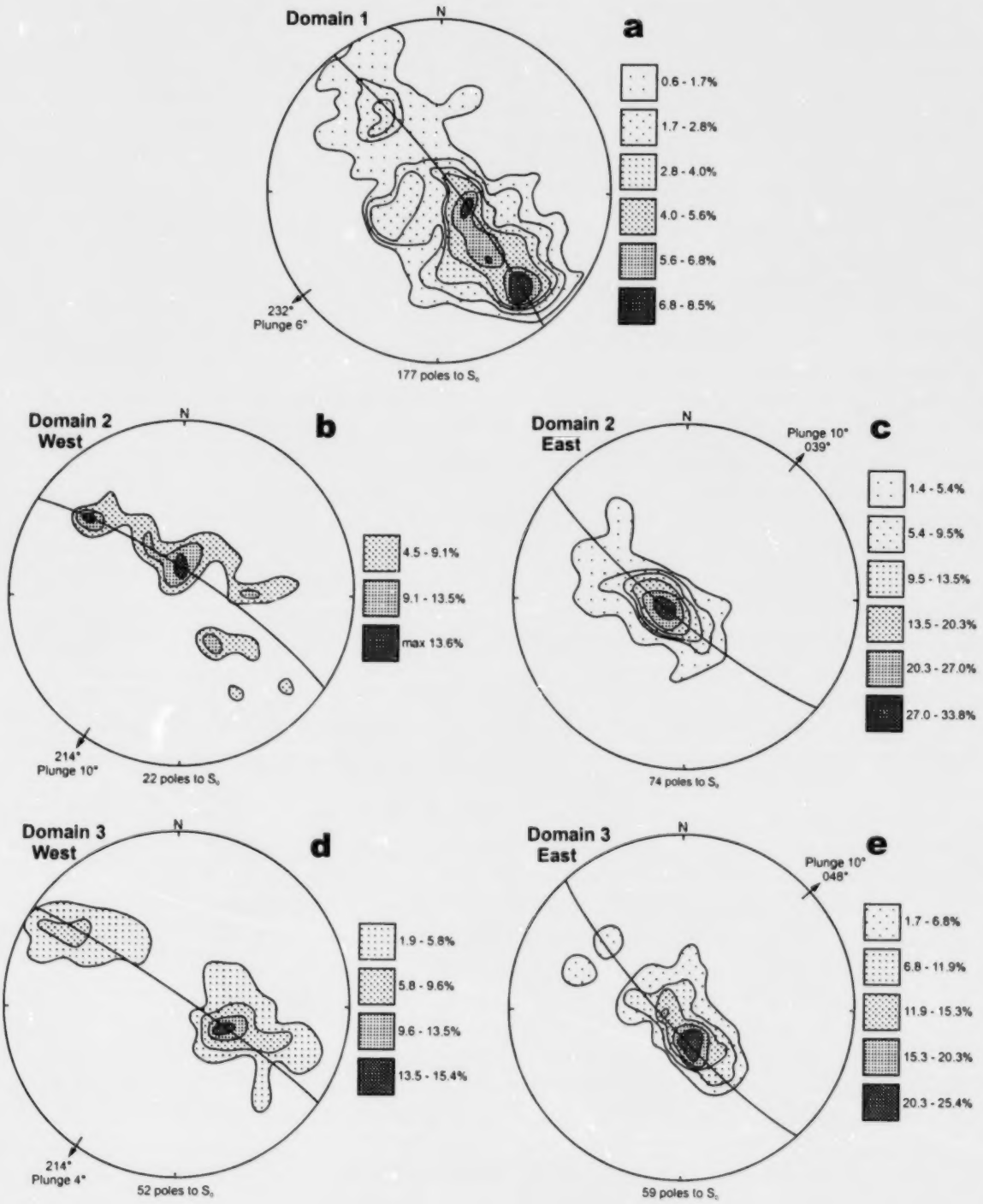


Figure 11. (a) to (e) Contoured distribution of poles to bedding for the Upsalquitch and White Head formations, Popelogan Lake–Lost Pine Lake area. See text for definition of domain boundaries.

Head formations along Goulette Brook. East of the axis of the Popelogan Anticline, sedimentary rocks of the White Head and Upsalquitch formations are shallowly dipping and gently folded (e.g., Narrows Brook Syncline, Figure 2); west of the anticlinal axis, strata are moderately to steeply dipping and folds are close to tight, with a prominent axial planar cleavage. For the purpose of structural analysis, the survey area has been divided into three domains bounded by major faults: domain 1 lies to the north of the Indian Lake Fault, domain 2 is situated between the Indian Lake and Arsenault Brook faults, and domain 3 is south of the Arsenault Brook Fault (Figure 2). Domains 2 and 3 have been further subdivided into sectors lying to the east and west of the Popelogan Anticline (Figure 11). All data were collected from the Upsalquitch and White Head formations, as the Popelogan and Goulette Brook formations exhibit no penetrative cleavage, and no bedding was observed.

A stereographic plot of 177 poles to bedding in domain 1 (Figure 11a) defines a northwest–southeast girdle, with most bedding planes dipping northwest at shallow to moderate angles. The pole to this girdle indicates a fold plunge of 6° toward 232° (Figure 11a). A subset of poles to bedding at the nose of the Popelogan Antiform (not shown), demonstrates that this structure plunges 25° toward 025°, though the data for this area are scanty. The anticline is evidently doubly plunging, as it plunges to the south near Little Popelogan Brook south of the survey area (Constable 1973b). In domains 2 and 3, plots of 96 poles to bedding in the former and 111 poles in the latter, illustrate that folds typically plunge 4°–10° to the southwest (214°) in the western part of the survey area, and 10° to the northeast (039°–048°) in the eastern part (Figures 11b, c, d, e). The most likely explanation of doubly plunging folds observed in all units is the superposition of Acadian folds on earlier, northwest-trending folds with no associated cleavage. Such folds have been documented in the Aroostook–Percé Anticlinorium in the Gaspé Peninsula (Malo and Bourque 1993) and western New Brunswick (Rast *et al.* 1980), and in the Chaleurs Group in the southern Gaspé Peninsula (Simard 1986).

The clustering of poles for the eastern parts of domains 2 and 3 shows that bedding dip-directions in this area range from east to northeast to northwest (Figures 11c, e). By comparison, on the west limb of the Popelogan Anticline, dips are moderate to the northwest or southeast (Figures 11b, d). Comparison of the average strike of fold axes reveals that in domain 1 there is a clockwise variation of about 18° compared to domains 2 and 3 on the south side of the Indian Lake Fault (Figures 11a, b, d).

A stereographic plot of 100 poles to cleavage in domain 1 indicates an average strike of 059° (Figure 12a), which is very close to the apparent strike of fold-axial surfaces, given the error in selection of the girdle axis caused by data scatter (Figure 11a). A plot of 22 poles to cleavage in domains 2 and 3 (Figure 12b) represents measurements taken to the west of the Popelogan Anticline, as the rocks on the east side exhibit no penetrative axial-planar cleavage. These data indicate an average strike of 034°, identical to the strike of fold-axial surfaces in this area. Cleavage in all domains dips steeply, and northwest dips predominate, indicating that folds are generally steeply inclined (asymmetrical) to the east. Like fold axial surfaces, as mentioned above, the average strike of cleavage in domain 1 varies by up to 25° (clockwise) from that in domains 2 and 3. This may be explained by asymmetry of the enveloping surface of minor or parasitic folds, combined with dextral movement on the Indian Lake Fault (Figure 13).

Several faults transect the survey area, including the Chouinard Brook, White Meadows, Indian Lake, South Charlo River, and Arsenault Brook faults (Figure 2). These faults have been interpreted mainly on the basis of outcrop distribution patterns, i.e., truncation or offset of units, and regional topographic

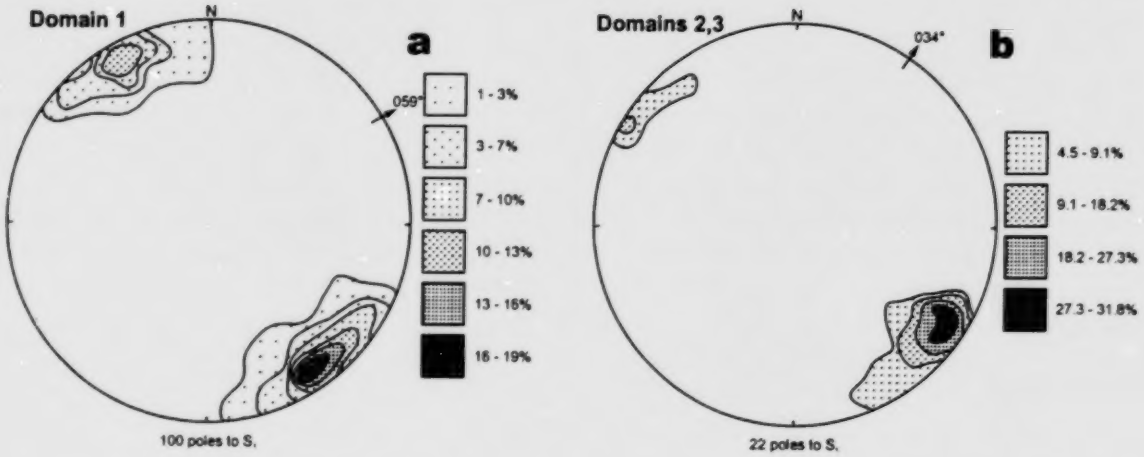


Figure 12. (a) and (b) Contoured distribution of poles to cleavage, Popelogan Lake–Lost Pine Lake area.

lineaments (e.g., the Chouinard Brook and White Meadows faults). The Indian Lake, South Charlo River and Arsenault Brook faults display dextral offsets both in the survey area and in the South Charlo River area to the east (J. Langton, personal communication). In addition, substantial downthrow must have occurred on the south side of the Arsenault Brook Fault, as the Goulette Brook Formation is cut out and replaced in the core of the Popelogan Anticline by a narrow belt of Popelogan Formation; furthermore, the Popelogan and White Head formations show abrupt changes in apparent thickness. Outcrop is very sparse in the topographic depressions commonly occupied by these faults, so fault kinematics are to a large extent unknown. The faults are assumed to be associated with mainly brittle deformation, as no shearing has been observed in rocks proximal to them, and some brecciation has been noted along the South Charlo River Fault to the east (J. Langton, personal communication). As discussed above, the contact between the Upsalquitch Formation and Bryant Point Formation in the southeast corner of the survey area has also been interpreted as a fault. This fault apparently originates to the south as a splay of the Rocky Brook–Millstream Fault, and is roughly parallel to the Jacquet River Fault (e.g., Irrinki 1990) farther east.

ECONOMIC GEOLOGY

Intrusion-related skarn alteration and mineralization

The most important economic mineralization in the survey area is the Popelogan copper skarn deposit (URNs 089, 1101 and 1102; Figure 2), which is hosted by shallowly dipping sedimentary rocks of the Upsalquitch and White Head formations near the western contact of the Red Brook Granodiorite. The host sedimentary rocks are also intruded by swarms of felsic to mafic dykes, sills, and cupolas or apophyses, that are genetically related to the main intrusive body. Contact metasomatic effects that accompany mineralization are manifest as hornfels and calc-silicate alteration (porcellanite and skarn) in a broad aureole enveloping most of the Red Brook Granodiorite and underlying an area of approximately 10 km^2 (stippled area, Figure 2). The history of discovery and exploration has been summarized by Logan (1969), Quartermain (1981) and Woods (1994), and will not be repeated in detail here. In total, 10 843 m of diamond drilling in 69 holes has been carried out since the discovery of an airborne EM anomaly by

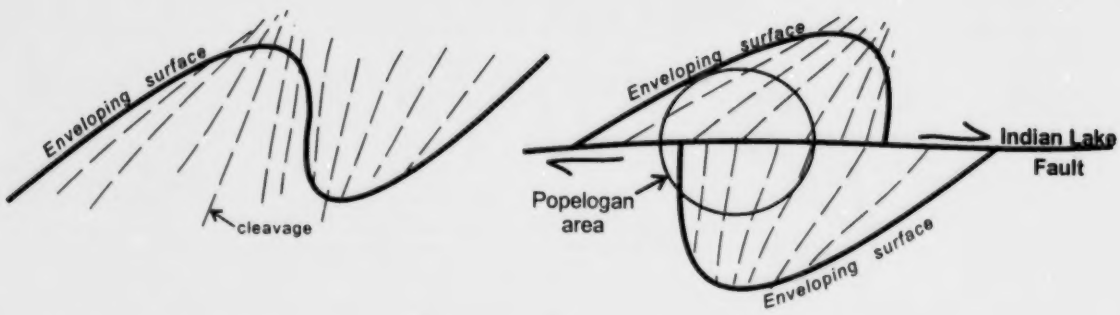


Figure 13. Schematic illustration of possible explanation for "rotation" of cleavage and fold axial surfaces north of the Indian Lake Fault.

Stratmat in 1954, during follow-up of an airborne magnetic anomaly identified by a GSC survey in 1951 (Mowat 1956). This number includes 25 holes by Stratmat Ltd. in 1955 (Mowat 1956), 24 holes by Kennco Explorations (Canada) Ltd. in 1961 (Perusse 1961), 6 holes by Augustus Exploration Ltd. in 1966 (Cheriton 1966), 7 holes by Noranda Exploration Co. Ltd. in 1969 (Logan 1970), 4 holes by Amax Minerals Exploration in 1979 (Sears 1982), 2 holes by Noranda Mining and Exploration Inc. in 1994 (Moore 1997), and one hole by Noranda Inc. in 1997 (Moore 1999). Two theses have examined aspects of the Popelogan deposit: Leslie (1963) studied the petrography and petrology of the intrusive and host sedimentary rocks as well as the metamorphic and metasomatic processes involved, whereas Quartermain (1981) focused on the nature and distribution of mineralization, and made recommendations for further work. A summary of this and other skarn-type deposits in northern New Brunswick has been presented by Woods (1993).

Three types of sulphide mineralization were described by Quartermain (1981): (1) massive, stratabound lenses and disseminations of pyrrhotite and chalcopyrite in a skarn zone located around one or more small apophyses of the Red Brook Granodiorite; (2) discontinuous pods of pyrrhotite cut by sulphide veins in hornfels and porcellanite; and (3) vein fillings in the intrusive rocks and hornfels/porcellanite, including massive pyrite–chalcopyrite veins and pyrite-chalcopyrite in quartz–carbonate veins. Several types of skarn have been documented, including a volumetrically dominant epidote–andradite skarn, a quartz–diopside skarn that hosts the best Cu grades, chlorite–calcite skarn, pyrrhotite–calcite skarn, tremolite skarn and an endoskarn (Quartermain 1981). Skarn mineralization in the main Popelogan deposit (URN 0089, Figure 2) constitutes the bulk of the known resource. A reserve estimate of 3 100 000 t of 0.3% Cu in two subzones has been reported by Quartermain (1981) and Sears (1982), although it is not clear who carried out the calculations or how they were done. The best sustained copper values were obtained from Stratmat hole 55-8, which yielded 0.53% Cu over 13.7 m, including 0.96% Cu over 4.6 m (Mowat 1956). Two skarn alteration zones have been recognized, one near surface, 15–30 m thick, carrying 20–30% sulphides, and a second zone 23–38 m thick and 240 to 400 m below surface, containing only minor magnetite, pyrite and chalcopyrite mineralization (Logan 1969). Therefore, one may assume that the tonnage figures given above were calculated from upper zone assay data. The Popelogan South occurrence (URN 1102, Figure 2) consists of pyrite, pyrrhotite, sphalerite and galena, and carries much higher values for lead, zinc and silver, including one intersection of 0.16% Cu, 3.50% Pb, 2.10% Zn and 0.44 oz. (12.5 g) Ag over 0.85 m in Stratmat hole 55-16 (Mowat 1956).

In addition to mineralization contained in skarn and hornfels, porphyritic phases of the Red Brook Granodiorite host chalcopyrite, pyrite, pyrrhotite, magnetite, molybdenite, scheelite and fluorite mineralization in quartz and quartz–carbonate vein networks (Sears 1982). Four holes were drilled by Amax to test a roughly circular magnetic feature with coincident geochemical anomalies; the best assays include 0.13% Mo over 1.5 m and 0.25% Cu over 3 m (Sears 1982). However, it was reported that numerous zones visually appeared to be of higher grade, but were not assayed in order "to preserve the core intact pending future direction of work."

Assays of drill core were carried out only for base metals, Au and Ag. To determine the range in values for other elements, one hundred core samples from 16 drill holes at Popelogan were collected during a metallogenic study undertaken in the Charlo–Popelogan area in the 1980s (Philpott 1987, 1988). The samples were analyzed for Cu, Pb, Zn, As, Sb, Bi, Mo, Ag, Au, Hg, Pt and Pd, but the data are as yet unpublished. Many elements, including Pb, As, Sb, Ag, Hg, Pd and Pt, are consistently low, as is Au, except in Stratmat hole 55-20 at URN 0089 (Figure 2), which has Au values up to 140 ppb along with 86 ppm Bi. Kennco holes 28, 31 and 32, also at or near URN 0089, locally contain very anomalous Mo (up to 1500, 160 and 230 ppm, respectively). During the same study, multi-element analysis was carried out on numerous samples of igneous and sedimentary rock from the Charlo–Popelogan region, especially those exhibiting some degree of alteration and mineralization, to evaluate the potential for other Popelogan-like deposits. No new possible skarn occurrences were thus discovered; however, the current mapping program has identified calc-silicate alteration in sedimentary rocks from two locations in the eastern part of the survey area (Figure 2).

Along the deep valley of Narrows Brook, a well-exposed 1-km sequence of very shallowly dipping Narrows Brook siltstones and sandstones contains abundant bedding-parallel bands of white to pale green porcellanite alteration, which constitutes about 5–10% of the section (at least 100 m true thickness). However, no intrusive rocks are exposed nearby. About 3.5 km to the south (just south of the Arsenault Brook Fault; Figure 2), porcellanite alteration was observed in an outcrop of Narrows Brook sedimentary rocks, 400 m east of an outcrop of diorite that chemically resembles the Red Brook Granodiorite. In both of these cases, alteration is presumed to have preferentially affected the more calcareous beds in the generally weakly calcareous rocks; this is supported by the anomalous abundance of CaO in the porcellanites compared to typical Narrows Brook rocks (Table 3), and the presence of secondary epidote, a common skarn mineral at the Popelogan deposit, in thin sections. Hornfelsed outcrops of sedimentary rock (and porcellanite in float) were also noted along a tributary of Narrows Brook, midway between the above porcellanite occurrences (Figure 2). The frequency of calc-silicate alteration in the eastern part of the survey area and adjacent areas to the north and east (e.g., Moore 1996) suggests the presence of one or more subjacent intrusive bodies. The latter may be similar in age and lithology to the Red Brook Granodiorite, based on isolated outcrops in the Narrows Brook area, as stated above, and in the South Charlo River area to the east (J. Langton, personal communication).

Whole-rock analysis was carried out on four samples of porcellanite (Table 3), including two from the Popelogan deposit, and two from the Narrows Brook occurrences cited above. Although comparisons with the Narrows Brook or White Meadows member are suspect because of uncertainty surrounding the composition of the porcellanite protolith, it is clear that the latter are relatively enriched in Fe_2O_3, MgO and Al_2O_3 compared to the unaltered sedimentary rocks. This is consistent with the conclusions of Leslie (1963) regarding the chemical changes accompanying metasomatism at the Popelogan deposit. The porcellanites also contain higher concentrations of base metals, TiO_2, Co, Ni, Sc, V and Sb, and are depleted in Ba and Sr. Assuming the porcellanite protolith was a calcareous siltstone similar to typical

White Meadows rocks, there is also some enrichment in SiO_2 and depletion in CaO. All of these chemical changes conform to those documented in typical mineralized skarn systems (Lentz 2000 and references therein).

Volcanic-associated base-metal occurrences

Base-metal occurrences in the Goulette Brook Formation include the Goulette Brook and Popelogan Lake occurrences (URNs 0091 and 0088, respectively; Figure 2), and mineralization recently intersected by drilling southwest of the Popelogan skarn deposit (Moore 1999). At the Goulette Brook occurrence, basalts and lapilli tuffs of the Goulette Brook Formation are intruded by feldspar porphyry dykes; prospecting led to discovery of sphalerite and galena in a brecciated felsic dyke. Several sulphide showings in mafic volcanic rocks were located by trenching, and the best grab samples assayed 0.20% Pb, 2.6% Zn and 275 ppm Cu (Tauchid 1970). One hole was drilled by Soquem to the southwest of the original showing; however, assays were generally low, with maximum base-metal values of 120 ppm Cu, 150 ppm Pb and 930 ppm Zn. A detailed account of rock, soil and stream geochemistry in this area was completed by Coker (1971). The Popelogan Lake occurrence consists of galena and sphalerite in a quartz–calcite vein cutting amygdaloidal basalt. The best assay from a grab sample yielded 0.32% Pb, 1.6% Zn and 142 ppm Cu (Tauchid 1970).

Drilling by Noranda in 1997 near the Popelogan deposit was intended to test for skarn-type mineralization associated with a conductive zone 600 m west of URN 1102 (Figure 2). Instead, the hole intersected a sequence of amygdaloidal basalts and pyrrhotite-rich mafic tuff/agglomerate, which constitutes a previously unknown inlier of the Goulette Brook Formation. Altered mafic tuffs were reported to contain 10–15% streaks, blebs and disseminations of pyrrhotite and sphalerite, and 1–2% pyrite and chalcopyrite (Moore 1999). The best mineralization is contained in a 21.7 m section grading 0.71% Zn and 0.11% Cu, including 7 m of 1.14% Zn and 0.12% Cu.

Goulette Brook basalts and tuffs host a number of other occurrences of sulphide mineralization (mainly pyrite), including, in one instance, a massive pyrite clast contained in lapilli tuff. Lithogeochemical analyses of grab samples of altered and/or mineralized rock (Philpott 1987, 1988, unpublished data) revealed anomalous base-metal values in several areas: (1) northeast of the Popelogan Lake occurrence—up to 116 ppm Cu, 174 ppm Pb, 1530 ppm Zn, 131 ppm As, 18 ppm Sb and 110 ppb Hg; (2) near the top of the Goulette Brook Formation west of Charlo River—159 ppm Cu and 250 ppb Hg; and (3) the narrow belt of Goulette Brook rocks near the southern boundary of the survey area—up to 173 ppm Cu and 44 ppb Au. Most of these anomalies occur at or near the top of the Goulette Brook Formation and the contact with the overlying Popelogan or White Head formations.

CONCLUSIONS

In the Popelogan Lake–Lost Pine Lake area, the Balmoral Group, consisting of Middle Ordovician subduction-related mafic volcanic rocks of the Goulette Brook Formation, and Upper Ordovician black shales and cherts of the Popelogan Formation, constitutes a window of Dunnage Zone basement (Popelogan Terrane) exposed in the core of the Popelogan Anticline. The Goulette Brook Formation is chemically heterogenous and comprises andesitic to basaltic amygdaloidal flows, and picritic, MgO-enriched, trace-element-depleted tuffs. The Popelogan Formation locally contains Caradocian graptolites of the *N. gracilis* zone, and hence is the same age as the lithologically similar Boucher Brook and Little River formations in the Bathurst Mining Camp (e.g., van Staal *et al.*, in press).

The Balmoral Group is disconformably overlain by Lower Silurian sedimentary rocks of the Gaspé Belt successor basin, including calcareous turbidites of the Matapédia Group and overlying calcareous to noncalcareous fine-grained clastic rocks belonging to the Upsalquitch Formation of the Chaleurs Group. Lithological and fossil evidence allows correlation with reference sections in the Gaspé Peninsula and indicates that the calcilutite, calcareous siltstone, shale and calcarenite of the Matapédia Group should be assigned to the L'Irlande Member of the White Head Formation. The Upsalquitch Formation is subdivided into three members, based on variations in lithology and sedimentology, and is interpreted as a deeper-water equivalent of the LaVieille Formation to the east. The White Head and Upsalquitch formations record a shallowing-upward succession of slope and outer- to inner-shelf sedimentation, reflecting crustal uplift accompanying closure of the Tetagouche–Exploits back-arc basin and breakoff of the subducting slab (van Staal and de Roo 1995). Chemical signatures of sedimentary rocks in the White Head and Upsalquitch formations indicate a substantial volcanic contribution in the terrestrial component of these rocks (probably derived from both the Popelogan arc and exhumed parts of the Tetagouche–Exploits back-arc basin), with increasing input from a more mature, continental source (Gander Zone?) over time. The Anticosti Platform is the probable source for the dominant carbonate component in the White Head Formation and at least the lower part of the Upsalquitch Formation; detrital carbonate in the upper part of the Upsalquitch Formation may have been derived, at least in part, from contemporaneous carbonate bank deposits of the LaVieille Formation.

The dominant structural feature in the area is the Popelogan Anticline, which plunges gently to the north-northeast. East of the anticlinal axis, rocks of the Upsalquitch Formation are shallowly dipping and very gently folded; the general structure here is a broad, open fold plunging gently to the northeast (Narrows Brook Syncline). Deformation of the Balmoral Group in the core of the anticline, and of White Head and Upsalquitch rocks to the east, is very weak, with no penetrative cleavage development. West of the hinge of the Popelogan Anticline, folds in the White Head and Upsalquitch formations are open to close, with moderate to strong axial-planar cleavage. The area is transected by several northeast-striking faults that offset or truncate units. One of these faults is interpreted to juxtapose the Upsalquitch Formation against younger rocks of the Chaleurs Group to the southeast.

Felsic to intermediate plutonic rocks of the Middle Devonian Red Brook Granodiorite intrude the Upsalquitch Formation in the southern part of the survey area; other intrusive rocks include felsic, intermediate and mafic dykes and sills that occur in all rock units. The Red Brook Granodiorite is a composite, multi-phase pluton with associated dykes, sills and apophyses that are genetically linked to the Popelogan copper skarn deposit near the western margin of the intrusion. It displays a wide compositional range, low abundance of HFSEs and sloping REE profiles typical of calc-alkalic, I-type (igneous-source) granitoids (Whalen *et al.* 1987; Whalen 1993) that are commonly associated with convergent plate margins. Dykes and sills form two distinct suites based on contrasting lithology and chemistry: microgranites with felsic compositions have flat REE profiles with prominent negative Eu anomalies and trace-element compositions typical of A-type (alkaline or anorogenic), within-plate granites (Whalen *et al.* 1987), whereas intermediate feldspar porphyries are chemically identical to the Red Brook Granodiorite. It is proposed, therefore, that the feldspar porphyries, like the Red Brook Granodiorite, are Middle Devonian in age, and that the microgranites, which chemically resemble Late Silurian to earliest Devonian intrusive rocks in northern New Brunswick, are considerably older.

Low-grade copper mineralization is hosted by a quartz–diopside skarn developed in the contact metasomatic aureole of the Red Brook Granodiorite. Pyrrhotite and pyrite are the most common sulphide minerals,

though sphalerite and galena are locally present in significant amounts. Molybdenite and scheelite occur in veins, primarily associated with porphyritic phases of the intrusion. Calc-silicate alteration (porcellanite) is locally extensive in the Narrows Brook member of the Upsalquitch Formation in the eastern part of the survey area; the alteration is bedding-parallel and occurs in thin bands, presumably affecting the more carbonate-rich beds in the generally weakly calcareous rocks. Whole-rock analysis indicates that the chemical changes accompanying alteration are the same as those in the vicinity of the Popelogan deposit. Several occurrences of low-grade base-metal mineralization are hosted by mafic volcanic rocks of the Goulette Brook Formation. Typically, mineralization is associated with lapilli tuffs, but has also been reported in amygdaloidal flows. Assays of mafic agglomerate from a hole drilled near the NBIP Road southwest of the Popelogan deposit yielded the best grades, at 0.71% Zn and 0.11% Cu over 21.7 m, including 7 m of 1.14% Zn and 0.12% Cu.

ACKNOWLEDGEMENTS

Steve McCutcheon and John Langton are thanked for critically reviewing the manuscript. Philip Evans and Terry Leonard drafted some of the figures. Field work was assisted by Graham Price. This paper is a contribution to the Appalachian Foreland and Platform NATMAP project.

REFERENCES

ALCOCK, F.J. 1935. Geology of Chaleur Bay region. Geological Survey of Canada, Memoir 183, 146 p.

AYRTON, W.G. 1967. Chandler–Port-Daniel area, Bonaventure and Gaspé-South counties. Quebec Department of Natural Resources, Geological Report 120, 91 p.

AYRTON, W.G., BERRY, W.B.N., BOUCOT, A.J., LAJOIE, J., LESPÉRANCE, P.J., PAVLIDES, L. and SKIDMORE, W.B. 1969. Lower Llandovery of the northern Appalachians and adjacent regions. Geological Society of America Bulletin, **80**: 459–484.

BEVIER, M.L. and WHALEN, J. 1990. Tectonic significance of Silurian magmatism in the Canadian Appalachians. Geology, **18**: 411–414.

BHATIA, M.R. 1983. Plate tectonics and geochemical composition of sandstones. The Journal of Geology, **91**: 611–627.

BHATIA, M.R. 1985. Rare earth element geochemistry of Australian Paleozoic greywackes and mudrocks: provenance and tectonic control. Sedimentary Geology, **45**: 97–113.

BHATIA, M.R and TAYLOR, S.R. 1981. Trace-element geochemistry and sedimentary provinces: a study from the Tasman geosyncline, Australia. Chemical Geology, **33**: 115–125.

BHATIA, M.R. and CROOK, K.A.W. 1986. Trace element characteristics of greywackes and tectonic setting discrimination of sedimentary basins. Contributions to Mineralogy and Petrology, **92**: 181–193.

BOUCOT, A.J. 1975. Evolution and extinction rate controls. *In* Developments in Paleontology and Stratigraphy, Volume 1. Elsevier Scientific Publishing Company, Amsterdam, 428 p.

BOUCOT, A.J., FIELD, M.T., FLETCHER, R., FORBES, W.H., NAYLOR, R.S. and PAVLIDES, L. 1964. Reconnaissance bedrock geology of the Presque Isle quadrangle, Maine. Maine Geological Survey, Quadrangle Mapping Series, No. 2, 123 p.

BOUMA, A.H. 1962. Sedimentology of Some Flysch Deposits. Elsevier Publishing Company, New York.

BOURQUE, P.-A. 1975. Lithostratigraphic framework and unified nomenclature for Silurian and basal Devonian rocks in eastern Gaspé Peninsula, Québec. Canadian Journal of Earth Sciences, **12**: 858–872.

BOURQUE, P.-A. and Lachambre, G. 1980. Stratigraphie du Silurien et du Dévonien basal du Sud de la Gaspésie, Québec. Ministère de l'Énergie et des Ressources Québec, ES-30, 123 p.

BOURQUE, P.-A., BRISEBOIS, D. and MALO, M. 1995. Gaspé Belt. *In* Chapter 4 of Geology of the Appalachian – Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, no. 6, pp. 316–351.

BOURQUE, P.-A., MALO, M and KIRKWOOD, D. 2000. Paleogeography and tectono-sedimentary history at the margin of Laurentia during Silurian to earliest Devonian time: the Gaspé Belt, Québec. Geological Society of America Bulletin, **112**: 4–20.

BURK, C.F. 1964. Silurian stratigraphy of Gaspé Peninsula, Québec. American Association of Petroleum Geologists Bulletin, **48:** 437–464.

CHERITON, C.G. 1966. Mining Licence 1101, diamond drill logs, for Augustus Exploration Ltd. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471956.

CLARKE, J.M. 1909. The Dalhousie Formation. *In* Early Devonic History of New York and Eastern North America. New York State Museum, Memoir 9, Part 2, pp. 7–51.

COKER, W.B. 1971. Cu, Pb, Zn, Ag, and Mn in the rocks, soils, and stream sediments in the area of the Goulette Brook Pb–Zn mineralization, New Brunswick. Unpublished B.Sc. thesis, Carleton University, Ottawa, Ontario, 73 p.

CONSTABLE, D. 1973a. Geology of map area L-3, St. Arthur, head of Charlo and Berry Brook (21 O/15). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 74-131.

CONSTABLE, D. 1973b. Geology of map area L-4, parts of Popelogan River and Lake (21 O/15). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 74-157.

CRICKMAY, G.W. 1932. Evidence of Taconic orogeny in Matapédia Valley, Québec. American Journal of Science, **24**: 368–386.

EGGINS, S.M. 1993. Origin and differentiation of picritic arc magmas, Ambae (Aoba), Vanuatu. Contributions to Mineralogy and Petrology, **114**: 79–100.

FRANCIS, D. 1995. The implications of picritic lavas for the mantle sources of terrestrial volcanism. Lithos, **34**: 89–105.

GIGGIE, K.V. (compiler) 1998. Geology of central Restigouche County, New Brunswick (NTS 21 O/10, 11, 14. 15, 16W), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-40.

GIGGIE, K.V. 1999. Ground follow-up to the multi-sensor airborne geophysical survey in central Restigouche County, New Brunswick: results and interpretation. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-9, 41 p.

GRABAU, A.W. 1903. Paleozoic coral reefs. Geological Society of America Bulletin, **14**: 337–352.

GREINER, H.R. 1967. Silurian–Devonian relationships of the Charlo map area, New Brunswick. *In* International Symposium on the Devonian System. *Edited by* D.H. Oswald. Alberta Society of Petroleum Geologists, Calgary, Alberta, Vol. 2, 973–979.

GREINER, H.R. 1970. Geology of the Charlo area (21 O/16), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Series 70-2, 18 p.

GREINER, H.R. 1974. Geology of Campbellton (21 O/15), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Plate 74-114.

HAMILTON-SMITH, T. 1970. Stratigraphy and structure of Ordovician and Silurian rocks of the Siegas area, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report of Investigation 12, 55 p.

HELMSTAEDT, H. 1971. Structural geology of the Portage Lakes area, Bathurst–Newcastle district, New Brunswick. Geological Survey of Canada, Paper 70-28, 52 p.

IRRINKI, R.R. 1973. Geology of map area M-3, upper parts of Charlo River and branches (21 O/15E, 21 O/16W). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 75-25.

IRRINKI, R.R. 1974. Geology of map area M-4, head of Charlo River, Red and Middle brooks (21 O/15E, 21 O/16W, 21 O/10E, 21 O/9W). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 75-76.

IRRINKI, R.R. 1976. Geology of Charlo (21 O/16) and parts of Atholville (21 O/15), Tetagouche Lakes (21 O/9), Upsalquitch Forks (21 O/10), and Pointe Verte (21 P/13) map areas, northern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 76-8 (revised 1990).

IRRINKI, R.R. 1990. Geology of the Charlo area, Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report of Investigation 24, 118 p.

KISS, F. 1998. Airborne electromagnetic, magnetic, gamma-ray spectrometer survey in the Restigouche area, northwestern New Brunswick. *In* Abstracts, 1998: 23rd annual Review of Activities. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 98-3, pp. 31–32.

LEE, H.J. and NOBLE, J.P.A. 1977. Silurian stratigraphy and depositional environments: Charlo–Upsalquitch Forks area, New Brunswick. Canadian Journal of Earth Sciences, **14**: 2533–2542.

LENTZ, D.R. 2000. Mass-balance considerations in mineralized skarn systems: implications for permeability evolution and carbonate mobility. GeoCanada 2000—The Millenium Geoscience Summit, Conference CD, Abstract No. 1037.

LENTZ, D.R., WALKER, J.A. and GOWER, S.J. 1993. Millstream Cu–Fe skarn deposit. *In*: Guidebook to the porphyry copper and copper skarn mineralization in northern New Brunswick and Gaspé, Québec. *Edited by* S.R. McCutcheon and G.A. Woods. Trip #1 of Bathurst '93: 3rd Annual Field Conference, Geological Society of CIM, pp. 22–40.

LESLIE, J.A. 1963. Contact alteration and mineralization of lime-rich sedimentary rocks in northern New Brunswick. Unpublished M.Sc. thesis, University of Western Ontario, London, Ontario, 87 p.

LESPÉRANCE, P.J., MALO, M., SHEEHAN, P.M. and SKIDMORE, W.B. 1987. A stratigraphical and faunal revision of the Ordovician–Silurian strata of the Percé area, Québec. Canadian Journal of Earth Sciences, **24:** 117–134.

LOGAN, C.M. 1969. Cheriton–Popelogan option, for Noranda Exploration Company Ltd. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471896.

LOGAN, C.M. 1970. Cheriton–Popelogan option, report on diamond drilling 1969, for Noranda Exploration Company Ltd. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471897.

MALO, M. 1988. Stratigraphy of the Aroostook–Percé Anticlinorium in the Gaspé Peninsula, Quebec. Canadian Journal of Earth Sciences, **25**: 893–908.

MALO, M. and BOURQUE, P.-A. 1993. Timing of the deformation events from Late Ordovician to Mid-Devonian in the Gaspé Peninsula. *In* The Acadian Orogeny: Recent Studies in New England, Maritime Canada, and the Autochthonous Foreland. E*dited by* D.C. Roy and J.W. Skehan. Geological Society of America, Special Paper 275, pp. 101–122.

MCCUTCHEON, S.R. and BEVIER, M.L. 1990. Implications of field relations and U–Pb geochronology for the age of gold mineralization and timing of Acadian deformation in northern New Brunswick. Atlantic Geology, **26**: 237–246.

MCLENNAN, S.M., TAYLOR, S.R., MCCULLOCH, M.T. and MAYNARD, J.B. 1990. Geochemical and Nd–Sr isotopic composition of deep-sea turbidites: crustal evolution and plate tectonic associations. Geochimica et Cosmochimica Acta, **54**: 2015–2050.

MCLENNAN, S.M. and TAYLOR, S.R. 1980. Th and U in sedimentary rocks: crustal evolution and sedimentary recycling. Nature, **285**: 621–624.

MESCHEDE, M. 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb–ZrY diagram. Chemical Geology, **56**: 207–218.

MOORE, C. 1996. Report of work, Charlo River claim group, for Noranda Inc New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 474813.

MOORE, C. 1997. Assessment report on the Popelogan Lake claim group, for Noranda Mining and Exploration Inc. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Assessment Report 474856.

MOORE, C. 1999. Assessment report on the Popelogan Lake claim group, for Noranda Inc. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 475179.

MOORHOUSE, W.W. 1955. Geological report, Popelogan property, for The American Metal Company Ltd. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471954.

MOSSMAN, D.J. and BACHINSKI, D.J. 1972. Zeolite facies metamorphism in the Silurian–Devonian fold belt of northeastern New Brunswick. Canadian Journal of Earth Sciences, **9**: 1703–1709.

MOWAT, J.R. 1956. Group 55—Popelogan Lake, for Stratmat Ltd. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471964.

NOBLE, J.P.A. 1976. Silurian stratigraphy and paleogeography, Pointe Verte area, New Brunswick, Canada. Canadian Journal of Earth Sciences, **13**: 537–546.

NOBLE, J.P.A. and HOWELLS, K.D.M. 1979. Early Silurian biofacies and lithofacies in relation to Appalachian basins in north New Brunswick. Bulletin of Canadian Petroleum Geology, **27**: 242–265.

NORTHROP, S.A. 1939. Paleontology and stratigraphy of the Silurian rocks of the Port-Daniel–Black Cape region, Gaspé. Geological Society of America, Special Paper 21, 302 p.

NOWLAN, G.S. 1981. Late Ordovician–Early Silurian conodont biostratigraphy of the Gaspé Peninsula—a preliminary report. *In* Field Meeting, Anticosti–Gaspé, 1981, Vol. 2: Stratigraphy and Paleontology. *Edited by* P.J. Lespérance. IUGS Subcommission on Silurian Stratigraphy and Ordovician–Silurian Boundary Working Group, Département de géologie, Université de Montréal, Montréal, Québec, pp. 257–291.

NOWLAN, G.S. 1983. Biostratigraphic, paleogeographic, and tectonic implications of Late Ordovician conodonts from the Grog Brook Group, northwestern New Brunswick. Canadian Journal of Earth Sciences, **20**: 651–671.

NOWLAN, G.S. 1988. Report on twelve samples from Lower Paleozoic strata of northern New Brunswick. Geological Survey of Canada, Report No. 011-GSN-1988, 6 p.

NYE, C.J. and REID, M.R. 1986. Geochemistry of primary and least fractionated lavas from Okmok volcano, central Aleutians: implications for arc magmagenesis. Journal of Geophysical Research, **91**, No. B10: 10 271–10 287.

OKULITCH, A.V. 1999. Geological time scale, 1999. Geological Survey of Canada, Open File 3040 (National Earth Science Series, Geological Atlas)—Revision.

PAVLIDES, L. 1965. Geology of the Bridgewater Quadrangle, Maine. United States Geological Survey, Bulletin 1206, 72 p.

PAVLIDES, L. 1968. Stratigraphic and facies relationships of the Carys Mills Formation of Ordovician and Silurian age, northeast Maine. United States Geological Survey, Bulletin 1264, 44 p.

PEARCE, J.A., HARRIS, N.B.W. and TINDLE, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology, **25**: 956–983.

PERUSSE, J. 1961. Assessment work report, Cheriton property, for Kennco Explorations (Canada) Ltd. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471958.

PHILPOTT, G.R. 1987. Precious-metal and geological investigation of the Charlo River area. *In* Twelfth Annual Review of Activities. *Edited by* S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 87-2, pp. 13–16.

PHILPOTT, G.R. 1988. Precious-metal and geological investigation of the Charlo River area. *In* Thirteenth Annual Review of Activities. *Edited by* S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 88-2, pp. 20–31.

PHILPOTT, G.R. 1990a. Charlo River project, geology of the Popelogan Lake area (NTS 21 O/15a), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 90-176.

PHILPOTT, G.R. 1990b. Charlo River project, geology of the Lost Pine Lake area (NTS 21 O/15b), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 90-175.

PICKERILL, R.K., FYFFE, L.R. and FORBES, W.H. 1987. Late Ordovician–Early Silurian trace fossils from the Matapedia Group, Tobique River, western New Brunswick, Canada. Maritime Sediments and Atlantic Geology, **23**: 77–88.

POTTER, R.R. 1965. Upsalquitch Forks map area, New Brunswick. Geological Survey of Canada, Map 14-1964 (with marginal notes).

QUARTERMAIN, R.A. 1981. Popelogan Lake, New Brunswick: property appraisal and proposal for further work. Unpublished M.Sc. thesis, Queen's University, Kingston, Ontario, 79 p.

RAMSAY, W.R.H., CRAWFORD, A.J. and FODEN, J.D. 1984. Field setting, mineralogy, chemistry, and genesis of arc picrites, New Georgia, Solomon Islands. Contributions to Mineralogy and Petrology, **88**: 386–402.

RAST, N., LUTES, G.G. and ST. PETER, C. 1980. The geology and deformation history of the southern part of the Matapedia Zone and its relationship to the Miramichi Zone and Canterbury Basin. *In* A Guidebook to the Geology of Northeastern Maine and Neighbouring New Brunswick. *Edited by* D.C. Roy and R.S. Naylor. 72nd Annual Meeting of the New England Intercollegiate Geological Conference, pp. 191–201.

RIVA, J. and MALO, M. 1988. Age and correlation of the Honorat Group, southern Gaspé Peninsula. Canadian Journal of Earth Sciences, **25**: 1618–1628.

RODGERS, J. 1970. The Tectonics of the Appalachians. New York, John Wiley and Sons, 271 p.

ROY, D.C. and MENCHER, E. 1976. Ordovician and Silurian stratigraphy of northeastern Aroostook County, Maine. Geological Society of America, Memoir 148, pp. 25–51.

ST. PETER, C.J. 1978. Geology of parts of Restigouche, Victoria and Madawaska counties, northwestern New Brunswick, NTS 21 N/8, 21 N/9, 21 O/5, 21 O/11, 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report of Investigation 17, 69 p.

SCHUCHERT, C. and DART, J.D. 1926. Stratigraphy of the Port Daniel–Gascons area of southeastern Québec. Geological Survey of Canada, Museum Bulletin no. 44, pp. 35–58.

SEARS, S.M. 1982. Report of work performed on the Popelogan property (Project 1029), for Amax Minerals Exploration. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 472878.

SIMARD, M. 1986. Géologie et évaluation du potential minéral de la région de Carleton. Ministère de l'Énergie et des Ressources du Québec, Étude ET 84-11, 27 p.

SKIDMORE, W.B. 1965. Honorat–Reboul area. Quebec Department of Natural Resources, GR 107.

SKIDMORE, W.B. and LESPÉRANCE, P.J. 1981. Percé area, the White Head Formation. *In* Field Meeting, Anticosti–Gaspé, 1981, Vol. 1: Guidebook. *Edited by* P.J. Lespérance. IUGS Subcommission on Siiurian Stratigraphy and Ordovician–Silurian Boundary Working Group, Département de géologie, Université de Montréal, Montréal, Québec, pp. 31–40.

STEPHENSON, E.M., MEINERT, L.D., MORTENSON, J.K. and HUSSEY, J. 1998. Age and skarn alteration of the Porphyry Mountain Cu–Mo deposit, Mines Gaspé, Québec. Geological Society of America, Abstracts with Programs, vol. 30, p. A-372.

STEWART, R.D. 1975. Petrology of Red Brook area, Restigouche County, New Brunswick. Unpublished B.Sc. thesis, Mount Allison University, Sackville, New Brunswick, 127 p.

STRINGER, P. and PICKERILL, R.K. 1980. Structure and sedimentology of Siluro-Devonian between Edmundston and Grand Falls, New Brunswick. *In* A Guidebook to the Geology of Northeastern Maine and Neighbouring New Brunswick. *Edited by* D.C. Roy and R.S. Naylor. 72nd Annual Meeting of the New England Intercollegiate Geological Conference, Presque Isle, Maine; Trip C-7, pp. 262–272.

SUN, S.S. 1982. Chemical composition and origin of the Earth's primitive mantle. Geochimica et Cosmochimica Acta, **46**: 179–192.

SUN, S.S. and MCDONOUGH, W.F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle compositions and processes. *In* Magmatism in the Ocean Basins. *Edited by* A.D. Saunders and M.J. Norry. Geological Society Special Publication No. 42, pp. 313–345.

TAUCHID, M. 1970. Project 11-716, Popelogan Lake claim group, for Soquem. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 471962.

TAYLOR, S.R. and MCLENNAN, S.M. 1985. The Continental Crust: Its Composition and Evolution. Blackwell, Oxford, 312 p.

TOONG, K.S. 1963. Volcanic rocks of the Red Brook area, Restigouche County, New Brunswick. Unpublished B.Sc. thesis, Carleton University, Ottawa, Ontario, 50 p.

TREMBLAY, A., MALO, M. and ST.-JULIEN, P. 1993. Dunnage Zone—Québec. *In* Geology of the Appalachian-Caledonian Orogen in Canada and Greenland. *Edited by* H. Williams. Geological Survey of Canada, Geology of Canada, no. 6, pp. 179–197.

VAN STAAL, C.R. and DE ROO, J.A. 1995. Mid-Paleozoic tectonic evolution of the Appalachian Central Mobile Belt in northern New Brunswick, Canada: collision, extensional collapse and dextral transpression. *In* Current Perspectives in the Appalachian–Caledonian Orogen. *Edited by* J.P. Hibbard, C.R. van Staal and P.A. Cawood. Geological Association of Canada, Special Paper 41, pp. 367–389.

VAN STAAL, C.R., WINCHESTER, J.A., and BÉDARD, J.H. 1991. Geochemical variations in Middle Ordovician volcanic rocks of the northern Miramichi Highlands and their tectonic significance. Canadian Journal of Earth Sciences, **28**: 1031–1049.

VAN STAAL, C.R., DEWEY, J.F., MAC NIOCAILL, C. and MCKERROW, W.S. 1998. The Cambrian–Silurian tectonic evolution of the northern Appalachians and British Caledonides: history of a complex, west and southwest Pacific-type segment of Iapetus. *In* Lyell: the Past is the Key to the Present. *Edited by* D.J. Blundell and A.C. Scott. Geological Society, London, Special Publications, **143:** 199–242.

VAN STAAL, C.R., WILSON, R.A., FYFFE, L.R., LANGTON, J.P., MCCUTCHEON, S.R., ROGERS, N., MCNICOLL, V. and RAVENHURST, C.E. (in press). Geology and tectonic history of the Bathurst Mining Camp and its relationships to coeval rocks in southwestern New Brunswick and adjacent Maine—a synthesis. *In* Massive Sulfide Deposits of the Bathurst Mining Camp, New Brunswick, and Northern Maine. *Edited by* W.D. Goodfellow, S.R. McCutcheon, and J.M. Peter. Economic Geology Monograph.

WALKER, J.A. and MCCUTCHEON, S.R. 1995. Siluro-Devonian stratigraphy of the Chaleur Bay Synclinorium, northern New Brunswick. *In* Current Research 1994. *Compiled and edited by* S.A.A. Merlini. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Miscellaneous Report 18, pp. 225–244.

WALKER, J.A., GOWER, S.J. and MCCUTCHEON, S.R. 1991. Antinouri–Nicholas project, Gloucester and Restigouche counties, northern New Brunswick. *In* Project summaries for 1991, Sixteenth Annual Review of Activities. *Edited by* S.A. Abbott. New Brunswick Department of Natural Resources and Energy, Mineral Resources, Information Circular 91-2, pp. 87–100.

WALKER, J.A., GOWER, S. and MCCUTCHEON, S.R. 1993. Antinouri Lake–Nicholas Denys project, Gloucester and Restigouche counties, New Brunswick. *In* Current Research. *Compiled and edited by* S.A. Abbott. New

Brunswick Department of Natural Resources and Energy, Mineral Resources, Information Circular 93-1, pp. 58–70.

WHALEN, J.B. 1993. Geology, petrography, and geochemistry of Appalachian granites in New Brunswick and Gaspésie, Québec. Geological Survey of Canada, Bulletin 436, 124 p.

WHALEN, J.B., CURRIE, K.L. and CHAPPELL, B.W. 1987. A-type granites: geochemical characteristics, discrimination and petrogenesis. Contributions to Mineralogy and Petrology, **95**: 407–419.

WHALEN, J.B., JENNER, G.A., HEGNER, E., GARIÉPY, C., and LONGSTAFFE, F.J. 1994. Geochemical and isotopic (Nd, O, and Pb) constraints on granite sources in the Humber and Dunnage zones, Gaspésie, Québec, and New Brunswick: implications for tectonics and crustal structure. Canadian Journal of Earth Sciences, **31**: 323–340.

WILSON, R.A. 1990. Geology of the New Denmark–Salmon River area, Victoria County, New Brunswick (parts of NTS 21 J/13, 21 J/14, 21 O/3, 21 O/4). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Report of Investigation 23, 67 p.

WILSON, R.A. 2000a. Preliminary geology of the Popelogan Lake area (NTS 21 O/15a), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-25.

WILSON, R.A. 2000b. Preliminary geology of the Lost Pine Lake area (NTS 21 O/15b), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-26.

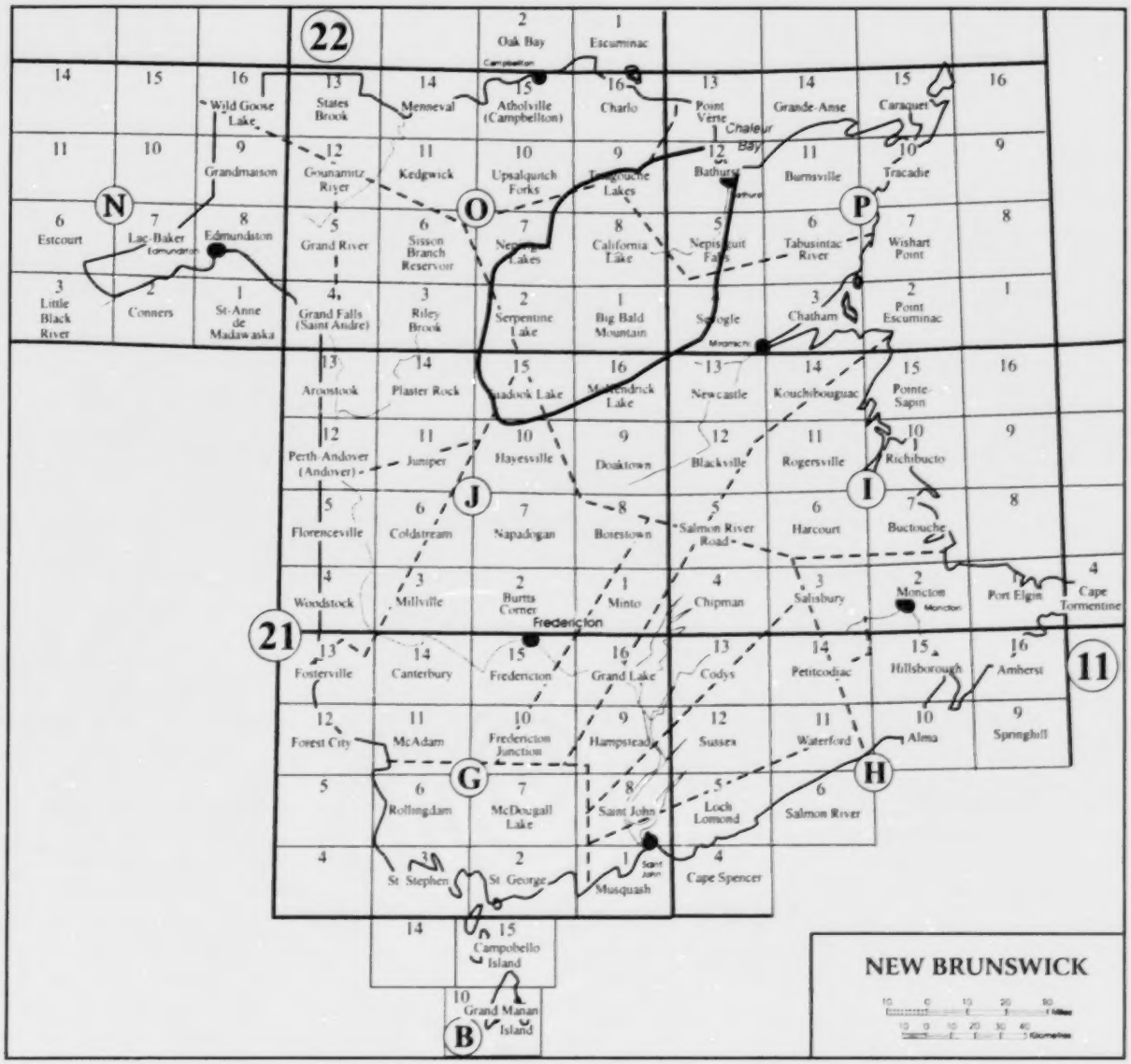
WINCHESTER, J.A. and FLOYD, P.A. 1977. Geochemical distribution of different magma series and their differentiation products using immobile elements. Chemical Geology, **20**: 325–343.

WOODS, G.A. 1993. Skarn type base metal deposits in the McKenzie Gulch, Patapedia and Popelogan areas. *In*: Guidebook to the porphyry copper and copper skarn mineralization in northern New Brunswick and Gaspé, Québec. *Edited by* S.R. McCutcheon and G.A. Woods. Trip #1 of Bathurst '93: 3rd Annual Field Conference, Geological Society of CIM, pp. 42–53.

WOODS, G.A. 1994. Report of work, Popelogan Lake group, for Brunswick Mining and Smelting Corp. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Exploration Report of Work, Assessment File 474421.

INDEX TO 1999–2000 PUBLICATIONS

ON THE GEOLOGY OF NEW BRUNSWICK



National Topographic System in New Brunswick showing the Bathurst Mining Camp

New Brunswick, General

CARROLL, B.M.W. (rédactrice) 1999. Rétrospective préliminaire de l'industrie minérale au Nouveau-Brunswick, 1998. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Rapport sur les ressources minérales 99-2, 26 p.

CARROLL, B.M.W. (editor) 1999. New Brunswick's mineral industry, 1998. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-3, 126 p.

CARROLL, B.M.W. (editor) 1999. Current Research 1998. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, 163 p.

CARROLL, B.M.W. (editor / rédactrice) 1999. Abstracts, 1999: 24th annual Review of Activities / Résumés, 1999 : 24e rétrospective annuelle des activités. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 99-3, 56 p. / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, 56 p.

CARROLL, B.M.W. (compiler) 1999. Major mineral developments in New Brusnwick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-32A [Scale: 1:500 000]

CARROLL, B.M.W. (compilatrice) 1999. Principaux gisements en voie d'exploitation au Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 99-32B [Échelle : 1:500 000]

CARROLL, B.M.W. (editor) 2000. Preliminary review of New Brunswick's mineral industry, 1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2000-1, 23 p.

HASSAN, H.H. 1999. Compilation of Bouguer gravity data for New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-33A [Scale: 1:1 000 000]

HASSAN, H.H. 1999. Compilation of Free-air gravity data for New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-33B [Scale: 1:1 000 000]

HASSAN, H.H. 2000. Digital compilation of gravity data for New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-1, 212 p. and digital data.

MCLEOD, M.J. and MCCUTCHEON, S.R. 2000. Gold environments in New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-28. [Approx. Scale: 1:1 250 000]

MCNEILL-DOBBELSTEYN, C.M. and CARROLL, B.M.W. (compilers) 2000. Directory of goods and services for the exploration industry in New Brunswick (February 2000). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2000-1, 12 p.

MCNEILL-DOBBELSTEYN, C.M. et CARROLL, B.M.W. (compilatrices) 2000. Répertoire des produits et des services offerts à l'industrie de l'exploration minérale au Nouveau-Brunswick (février 2000). Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Circulaire d'information 2000-2, 14 p.

MERLINI, S.A.A. (compiler) 1999. New Brunswick computerized mineral occurrence database (revised 1999). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-12, digital mineral occurrence files.

MERLINI, S.A.A. (compiler) 1999. Available mineral properties in New Brunswick (revised January 1999). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Reference 130, 181 p.

MINERALS AND METALS SECTOR. 1999. Promising new mines in Canada, 1999–2002. Geological Survey of Canada, Map 2000A [Scale: 1:6 000 000]

MINISTÈRE DES RESSOURCES NATURELLES ET DE L'ÉNERGIE DU NOUVEAU-BRUNSWICK. 1999. Tracé du gazoduc et des embrancements proposées. Division des ressources minières et de l'énergie, Planche 98-71.

MINISTÈRE DES RESSOURCES NATURELLES ET DE L'ÉNERGIE DU NOUVEAU-BRUNSWICK. 2000. Carte normalisée de quadrillage pour le pétrole et gaz naturel du Nouveau-Brunswick, tenure—pétrole et gaz naturel. Division des ressources minières et de l'énergie, Planche 98-72A. [Échelle : 1:600 000]

MINISTÈRE DES RESSOURCES NATURELLES ET DE L'ÉNERGIE DU NOUVEAU-BRUNSWICK. 2000. Carte normalisée de quadrillage pour le pétrole et gaz naturel du Nouveau-Brunswick, tenure—schistes bitumineux. Division des ressources minières et de l'énergie, Planche 98-72B. [Échelle : 1:600 000]

MINISTÈRE DES RESSOURCES NATURELLES ET DE L'ÉNERGIE DU NOUVEAU-BRUNSWICK. 2000. Carte normalisée de quadrillage pour le pétrole et gaz naturel du Nouveau-Brunswick, tenure—stockage souterrain. Division des ressources minières et de l'énergie, Planche 98-72C. [Échelle : 1:600 000]

NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES AND ENERGY. 1999. Pipeline route and proposed laterals. Minerals and Energy Division, Plate 98-71.

NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES AND ENERGY. 2000. New Brunswick standard oil and natural gas grid map, oil and natural gas tenure. Minerals and Energy Division, Plate 98-72A. [Scale: 1: 600 000]

NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES AND ENERGY. 2000. New Brunswick standard oil and natural gas grid map, bituminous shale tenure. Minerals and Energy Division, Plate 98-72B. [Scale: 1: 600 000]

NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES AND ENERGY. 2000. New Brunswick standard oil and natural gas grid map, underground storage tenure. Minerals and Energy Division, Plate 98-72C. [Scale: 1: 600 000]

OAKLEY, G.N. (compiler) 1999. Morphology map, topography/bathymetry, Atlantic Region, Canada. Geological Survey of Canada, Open File 3774, 1 map in colour [Scale: 1:3 000 000]

PE-PIPER, G. and PIPER, D.J.W. 1999. Were Jurassic tholeiitic lavas originally widespread in southeastern Canada?: a test of the broad terrane hypothesis. Canadian Journal of Earth Sciences, **36**: 1509–1516.

RAMPTON, V.N., GAUTHIER, R.C., THIBAULT, J. and SEAMAN, A.A. 2000. Physiography of New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-27. [Scale: 1:1 000 000]

ST. PETER, C. 2000. Oil shales and oil and natural gas in New Brunswick: historical and current industry-related activities. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2000-5, 18 p. (parts of 21 G and 21 H)

ST. PETER, C. 2000. Carboniferous geology of the southwestern New Brunswick Platform (Marysville Subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16. (parts of NTS 21 G and 21 H) [Scale: 1: 150 000]

ST. PETER, C. and PHILLIPS, R. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-7, 39 p. (parts of NTS 21 B, 21 G, 21 H, 21 I, 21 P)

WEBB, T.C. 2000. Developing New Brunswick's stone resource: a down-to-earth approach. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2000-3, 7 p.

Bathurst Mining Camp, General

CONNELL, S., KATSUBE, T.J., and HUNT, P.A. 1999. Textural characteristics of low to high resistivity, low anisotropy volcanic tuffs, Bathurst mining camp, New Brunswick. *In* Current Research 1999-E. Geological Survey of Canada, pp. 175–181.

CONNELL, S., KATSUBE, T.J., and HUNT, P.A. 1999. Textural characteristics of moderate to strongly foliated volcanic tuffs that display high resistivity and anisotropy values, Bathurst mining camp, New Brunswick. *In* Current Research 1999-E. Geological Survey of Canada, pp. 183–188.

CONNELL, S., KATSUBE, T.J., and HUNT, P.A. 1999. Textural characteristics of low to high resistivity sedimentary rocks, Bathurst mining camp, New Brunswick. *In* Current Research 1999-E. Geological Survey of Canada, pp. 189–194.

LANGTON, J.P., BANKS, P.G. and VAN DE POLL, R. 1999. The EXTECH II Geoscience Database Viewer (CD-ROM), Bathurst Mining Camp, northern New Brunswick, Canada (Mineral Resource Report 99-5). *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 35–36.

11 L/04, Cape Tormentine

JOHNSON, S.C. 1999. $^{40}Ar/^{39}Ar$ dating of detrital muscovite from post-Viséan (Carboniferous) sandstones in southeastern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 19–34.

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 B, EASTPORT

PHILLIPS, R.E. and ST. PETER, C. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999; Eastport: map sheet 21 B with northwest corner of Annapolis map sheet 21 A. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-20A. [Scale: 1:250 000]

21 B/10, Grand Manan Island

BÉRUBÉ, D. 1999. Photogrammetric study of coastline changes along Castalia Beach, Grand Manan Island, New Brunswick: 1945–1984. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-28A [Scale: 1:10 000]

BÉRUBÉ, D. 1999. Photogrammetric study of shoreline changes along Castalia Beach, Grand Manan Island, New Brunswick: 1945–1984. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-28B [Scale: 1:10 000]

21 B/15, Campobello

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 G, FREDERICTON

Phillips, R.E. and St. Peter, C. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999; Fredericton: map sheet 21 G. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-20B. [Scale: 1:250 000]

St. Peter, C. 2000. Oil shales and oil and natural gas in New Brunswick: historical and current industry-related activities. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2000-5, 18 p. (parts of 21 G and 21 H)

St. Peter, C. 2000. Carboniferous geology of the southwestern New Brunswick Platform (Marysville Subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16. (parts of NTS 21 G and 21 H) [Scale: 1: 150 000]

St. Peter, C. and Phillips, R. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-7, 39 p. (parts of NTS 21 B, 21 G, 21 H, 21 I, 21 P)

New Brunswick Department of Natural Resources and Energy. 1999. Province of New Brunswick oil and natural gas rights, Fredericton (NTS 21 G). Minerals and Energy Division, Plate 98-75B. [Scale: 1: 150 000]

21 G/01, Musquash

Barr, S.M., White, C.E. and McLeod, M.J. 1999. Geology of the Silurian Kingston terrane, southern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 1–17.

Currie, K.L. and McNicoll, V.J. 1999. New data on the age and geographic distribution of Neoproterozoic plutons near Saint John, New Brunswick. Atlantic Geology, **35**: 157–166.

Webb, T.C. 1999. Geology and limestone/dolomite deposits of the Lorneville Peninsula area, Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-24E [Scale: 1:10 000]

Webb, T.C. 2000. Precambrian limestones and dolomites of New Brunswick: geology and development potential. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 97-15, 227 p.

21 G/02, St. George

Barr, S.M., White, C.E. and McLeod, M.J. 1999. Geology of the Silurian Kingston terrane, southern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 1–17.

CURRIE, K.L. and MCNICOLL, V.J. 1999. New data on the age and geographic distribution of Neoproterozoic plutons near Saint John, New Brunswick. Atlantic Geology, **35**: 157–166.

FYFFE, L.R., PICKERILL, R.K. and STRINGER, P. 1999. Stratigraphy, sedimentology and structure of the Oak Bay and Waweig formations, Mascarene Basin: implications for the paleotectonic evolution of southwestern New Brunswick. Atlantic Geology, **35**: 59–84.

21 G/08, Saint John

BARR, S.M., WHITE, C.E. and MCLEOD, M.J. 1999. Geology of the Silurian Kingston terrane, southern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 1–17.

CURRIE, K.L. and MCNICOLL, V.J. 1999. New data on the age and geographic distribution of Neoproterozoic plutons near Saint John, New Brunswick. Atlantic Geology, **35**: 157–166.

JOHNSON, S.C. 2000. Bedrock geology of the Long Reach area (parts of NTS 21 G/08a, b, g, and h), southern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-17. [Scale: 1:20 000]

JOHNSON, S.C. 2000. Bedrock geology of the Loch Alva–Nerepis area (parts of NTS 21 G/08c, d, e and f), southern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-18. [Scale: 1:20 000]

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

WEBB, T.C. 1999. General geology and limestone/dolomite deposits of the Ketepec–South Bay area, Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-24A [Scale: 1:10 000]

WEBB, T.C. 1999. Geology and limestone/dolomite deposits of the Green Head Island–Saint John (east & west) area, Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-24C [Scale: 1:10 000]

WEBB, T.C. 1999. Geology and limestone/dolomite deposits of the East Saint John area, Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-24D [Scale: 1:10 000]

WEBB, T.C. 2000. Precambrian limestones and dolomites of New Brunswick: geology and development potential. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 97-15, 227 p.

21 G/09, Hampstead

MCLEOD, M.J. 2000. New mineral occurrence west of Evandale, Queens County, New Brunswick: South Hamilton Road, Au, Ag, Zn, Cu, Pb (URN 1412). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-23. [Scale: 1:50 000]

21 G/10, Fredericton Junction

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 G/11, McAdam

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 G/13, Fosterville

FYFFE, L.R. 1999. Geology of the Eel River area (part of NTS 21 G/13h), York and Carleton counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-30 [Scale: 1:10 000]

21 G/15, Fredericton

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 G/16, Grand Lake

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 H, SUSSEX

PHILLIPS, R.E. and ST. PETER, C. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999; Amherst: map sheet 21 H. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-20C. [Scale: 1:250 000]

ST. PETER, C. 2000. Oil shales and oil and natural gas in New Brunswick: historical and current industry-related activities. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 2000-5, 18 p. (parts of 21 G and 21 H)

ST. PETER, C. 2000. Carboniferous geology of the southwestern New Brunswick Platform (Marysville Subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16. (parts of NTS 21 G and 21 H) [Scale: 1: 150 000]

ST. PETER, C. and PHILLIPS, R. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-7, 39 p. (parts of NTS 21 B, 21 G, 21 H, 21 I, 21 P)

New Brunswick Department of Natural Resources and Energy. 1999. Province of New Brunswick oil and natural gas rights, Sussex (NTS 21 H). Minerals and Energy Division, Plate 98-75C. [Scale: 1: 150 000]

New Brunswick Department of Natural Resources and Energy. 1999. Province of New Brunswick bituminous shale rights, Sussex (NTS 21 H). Minerals and Energy Division, Plate 98-76C. [Scale: 1: 150 000]

New Brunswick Department of Natural Resources and Energy. 1999. Province of New Brunswick underground storage rights, Sussex (NTS 21 H). Minerals and Energy Division, Plate 98-77C. [Scale: 1: 150 000]

21 H/4, Cape Spencer

Barr, S.M. and White, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

McLeod, M.J. and Johnson, S.C. 1999. Bedrock geological compilation of the Cape Spencer map area (NTS 21 H/04), Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-17 [Scale: 1:50 000]

21 H/05, Loch Lomond

Barr, S.M. and White, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

Barr, S.M., White, C.E. and McLeod, M.J. 1999. Geology of the Silurian Kingston terrane, southern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 1–17.

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

Webb, T.C. 1999. Geology and limestone/dolomite deposits of the Elliott Road–Hammond River–Nauwigewauk area, Kings County, New Brunswick (part of NTS 21 H/5). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-24B [Scale: 1:12 500]

Webb, T.C. 1999. Geology and limestone/dolomite deposits of the Nauwigewauk area, Kings County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 97-24F [Scale: 1:3 300]

McLeod, M.J. and Johnson, S.C. 1999. Bedrock geological compilation of the Loch Lomond map area (NTS 21 H/05), Saint John and Kings counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-18 [Scale: 1:50 000]

Webb, T.C. 2000. Precambrian limestones and dolomites of New Brunswick: geology and development potential. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 97-15, 227 p.

21 H/6, Salmon River

Barr, S.M. and White, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

McLeod, M.J. and Johnson, S.C. 1999. Bedrock geological compilation of the Salmon River map area (NTS 21 H/06), Saint John County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-19 [Scale: 1:50 000]

21 H/10, Alma

Barr, S.M. and White, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

McLeod, M.J. and Johnson, S.C. 1999. Bedrock geological compilation of the Alma map area (NTS 21 H/10), Albert County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-25 [Scale: 1:50 000]

21 H/11, Waterford

Barr, S.M. and White, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

McLeod, M.J. and Johnson, S.C. 1999. Bedrock geological compilation of the Waterford map area (NTS 21 H/11), Saint John, Kings, and Albert counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-20 [Scale: 1:50 000]

21 H/12, Sussex

Barr, S.M. and White, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

Barr, S.M., White, C.E. and McLeod, M.J. 1999. Geology of the Silurian Kingston terrane, southern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 1–17.

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

McLeod, M.J. and Johnson, S.C. 1999. Bedrock geological compilation of the Sussex map area (NTS 21 H/12), Kings and Queens counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-21 [Scale: 1:50 000]

Venugopal, D.V. 1999. Drill hole location and drill hole information, Cassidy Lake silica deposit, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-31 [Scale: 1:500 approx.]

Webb, T.C. 2000. Precambrian limestones and dolomites of New Brunswick: geology and development potential. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 97-15, 227 p.

21 H/13, Codys

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

MCLEOD, M.J. and JOHNSON, S.C. 1999. Bedrock geological compilation of the Codys map area (NTS 21 H/13), Kings and Queens counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-22 [Scale: 1:50 000]

21 H/14, Petitcodiac

ALLABY, G.M. 2000. Till provenance and glacial history of the Petitcodiac (NTS 21 H/14) map area, southeastern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-8, 217 p.

BARR, S.M. and WHITE, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

MCLEOD, M.J. and JOHNSON, S.C. 1999. Bedrock geological compilation of the Petitcodiac map area (NTS 21 H/14), Kings, Westmorland and Queens counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-23 [Scale: 1:50 000]

21 H/15, Hillsborough

BARR, S.M. and WHITE, C.E. 1999. Field relations, petrology, and structure of Neoproterozoic rocks in the Caledonian Highlands, southern New Brunswick. Geological Survey of Canada, Bulletin 530, 101 p.

JOHNSON, S.C. 1999. $^{40}Ar/^{39}Ar$ dating of detrital muscovite from post-Viséan (Carboniferous) sandstones in southeastern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 19–34.

MCLEOD, M.J. and JOHNSON, S.C. 1999. Bedrock geological compilation of the Hillsborough map area (NTS 21 H/15), Albert and Westmorland counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-26 [Scale: 1:50 000]

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 H/16, Amherst

JOHNSON, S.C. 1999. $^{40}Ar/^{39}Ar$ dating of detrital muscovite from post-Viséan (Carboniferous) sandstones in southeastern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 19–34.

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I, MONCTON

St. Peter, C. and Phillips, R. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-7, 39 p. (parts of NTS 21 B, 21 G, 21 H, 21 I, 21 P)

New Brunswick Department of Natural Resources and Energy. 1999. Province of New Brunswick oil and natural gas rights, Moncton (NTS 21 I). Minerals and Energy Division, Plate 98-75D. [Scale: 1: 150 000]

New Brunswick Department of Natural Resources and Energy. 1999. Province of New Brunswick underground storage rights, Moncton (NTS 21 I). Minerals and Energy Division, Plate 98-77C. [Scale: 1: 150 000]

Phillips, R.E. and St. Peter, C. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999; Moncton: map sheet 21 I. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-20D. [Scale: 1:250 000]

21 I/01, Port Elgin

Johnson, S.C. 1999. $^{40}Ar/^{39}Ar$ dating of detrital muscovite from post-Viséan (Carboniferous) sandstones in southeastern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 19–34.

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/02, Moncton

Johnson, S.C. 1999. $^{40}Ar/^{39}Ar$ dating of detrital muscovite from post-Viséan (Carboniferous) sandstones in southeastern New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 19–34.

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/03, Salisbury

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/04, Chipman

MILLER, R.F. 1999. Report of *Gyracanthus* (Chordata: Acanthodii) and other Upper Carboniferous fish from the Minto Formation, New Brunswick (NTS 21 I/4). *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 37–43.

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/05, Salmon River Road

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/06, Harcourt

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/07, Bouctouche

BÉRUBÉ, D., ROBICHAUD, A., EVANS, P., and/et CHIASSON, M. 2000. Variations de la position du front dunaire le long de la flèche de Bouctouche, côte sud-est du Nouveau-Brunswick / Variations in the position of the dune face along the Bouctouche Spit, southeast coast of New Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-24 / New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-24. [Échelle / scale: 1:10 000]

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/10, Richibucto

BÉRUBÉ, D., ROBICHAUD, A., EVANS, P., and/et CHIASSON, M. 2000. Variations de la position du front dunaire le long de la flèche de Bouctouche, côte sud-est du Nouveau-Brunswick / Variations in the position of the dune face along the Bouctouche Spit, southeast coast of New Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-24 / New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-24. [Échelle / scale: 1:10 000]

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/11, Rogersville

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/12, Blackville

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/13, Newcastle

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/14, Kouchibouguac

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 I/15, Pointe-Sapin

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 J, WOODSTOCK

NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES AND ENERGY. 1999. Province of New Brunswick oil and natural gas rights, Woodstock (NTS 21 J). Minerals and Energy Division, Plate 98-75E. [Scale: 1: 150 000]

PHILLIPS, R.E. and ST. PETER, C. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999; Woodstock: map sheet 21 J. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-20E. [Scale: 1:250 000]

21 J/01, Minto

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 J/02, Burtts Corner

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 J/03, Millville

SEAMAN, A.A. 1999. Follow-up till geochemistry in the Millville (NTS 21 J/3) map area, York County, New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 45–55.

SEAMAN, A.A. 1999. Till geochemistry of the Millville (NTS 21 J/3) map area, York and Carleton counties, New Brunswick: site and geochemical data. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-11, 83 p. and digital data.

21 J/04, Woodstock

SEAMAN, A.A. 2000. Till geochemistry of the New Brunswick part of the Woodstock (NTS 21 J/04) map area, Carleton County, New Brunswick: site and geochemical data. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-3, 45 p. and digital data.

SEAMAN, A.A. 2000. Till geochemistry sample site in the New Brunswick part of the Woodstock (NTS 21 J/04) map area, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-19. [Scale: 1: 50 000]

21 J/07, Napadogan

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 J/08, Boiestown

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 J/09, Doaktown

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 J/16, McKendrick Lake

St. Peter, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 N, EDMUNDSTON

New Brunswick Department of Natural Resources and Energy. 1999. Province of New Brunswick oil and natural gas rights, Edmundston (NTS 21 N). Minerals and Energy Division, Plate 98-75F. [Scale: 1: 150 000]

21 O/01, Big Bald Mountain

Doiron, A. 2000. Surficial geology, Big Bald Mountain–Sevogle, New Brunswick, NTS 21 O/01 and part of 21 P/04. Geological Survey of Canada, Map 1977A [Scale: 1:50 000]

Wilson, R.A., Fyffe, L.R., McNicoll, V. and Wodicka, N. 1999. Lithogeochemistry, petrography and geochronology of Ordovician rocks in the Big Bald Mountain area (NTS 21 O/1), Bathurst Mining Camp, New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 89–142.

21 O/02, Serpentine Lake

Doiron, A. 2000. Surficial geology, Serpentine Lake, New Brunswick, NTS 21 O/02. Geological Survey of Canada, Map 1976A [Scale: 1:50 000]

21 O/4, Grand Falls

New Brunswick Department of Public Works. 1961. Report on surface investigation for Pleistocene stratigraphy, Grand Falls, (21 O/4). Development Engineering Branch, 18 p.

21 O/07, Nepisiguit Lakes

Leybourne, M.L., Goodfellow, W.D., Boyle, D.R., and Dunn, C.E. 1999. Stream water, stream sediment, and vegetation geochemistry of the Restigouche–Murray Brook area, Bathurst Mining Camp, New Brunswick (parts of NTS 21 O/07, 21 O/8, 21 O/9, and 21 O/10). Geological Survey of Canada, Open File D3763, digital data (1 CD-ROM).

van Staal, C.R. 2000. Geology, northern half of the Bathurst Mining Camp (part of NTS 21 O/07, 8, 9, 10, 21 P/5, 12), New Brunswick. Geological Survey of Canada, Open File 3839, 8 maps in colour. [Scale: 1:20 000]

21 O/08, California Lakes

LEYBOURNE, M.L., GOODFELLOW, W.D., BOYLE, D.R., and DUNN, C.E. 1999. Stream water, stream sediment, and vegetation geochemistry of the Restigouche–Murray Brook area, Bathurst Mining Camp, New Brunswick (parts of NTS 21 O/07, 21 O/8, 21 O/9, and 21 O/10). Geological Survey of Canada, Open File D3763, digital data (1 CD-ROM).

VAN STAAL, C.R. 2000. Geology, northern half of the Bathurst Mining Camp (part of NTS 21 O/07, 8, 9, 10, 21 P/5, 12), New Brunswick. Geological Survey of Canada, Open File 3839, 8 maps in colour. [Scale: 1:20 000]

WALKER, J.A. 1999. Geology of the Taylor Brook massive-sulphide deposit (NTS 21 O/08E), Bathurst Mining Camp, New Brunswick. *In* Current Research 1998. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 57–87.

21 O/09, Tetagouche Lakes

LEYBOURNE, M.L., GOODFELLOW, W.D., BOYLE, D.R., and DUNN, C.E. 1999. Stream water, stream sediment, and vegetation geochemistry of the Restigouche–Murray Brook area, Bathurst Mining Camp, New Brunswick (parts of NTS 21 O/07, 21 O/8, 21 O/9, and 21 O/10). Geological Survey of Canada, Open File D3763, digital data (1 CD-ROM).

VAN STAAL, C.R. 2000. Geology, northern half of the Bathurst Mining Camp (part of NTS 21 O/07, 8, 9, 10, 21 P/5, 12), New Brunswick. Geological Survey of Canada, Open File 3839, 8 maps in colour. [Scale: 1:20 000]

21 O/10, Upsalquitch Forks

FRISKE, P.W.B., DAY, S.J.A., PRONK, A.G., MCCURDY, M.W. and BOLDON, R. 1999. Regional Geochemical Reconnaissance—Multi-element stream sediment data plot: Restigouche area, New Brunswick, NTS 21 O/10, 11, 14, 15, 16(W). Geological Survey of Canada, Open File 3820, 2 maps in colour (Sheet 1: Ag, As, Au, Pb, Sb, Zn; Sheet 2: Co, Cr, Cu, Ni). [Scale: 1:100 000]

LEYBOURNE, M.L., GOODFELLOW, W.D., BOYLE, D.R., and DUNN, C.E. 1999. Stream water, stream sediment, and vegetation geochemistry of the Restigouche–Murray Brook area, Bathurst Mining Camp, New Brunswick (parts of NTS 21 O/07, 21 O/8, 21 O/9, and 21 O/10). Geological Survey of Canada, Open File D3763, digital data (1 CD-ROM).

VAN STAAL, C.R. 2000. Geology, northern half of the Bathurst Mining Camp (part of NTS 21 O/07, 8, 9, 10, 21 P/5, 12), New Brunswick. Geological Survey of Canada, Open File 3839, 8 maps in colour. [Scale: 1:20 000]

21 O/11, Kedgwick

FRISKE, P.W.B., DAY, S.J.A., PRONK, A.G., MCCURDY, M.W. and BOLDON, R. 1999. Regional Geochemical Reconnaissance—Multi-element stream sediment data plot: Restigouche area, New Brunswick, NTS 21 O/10, 11, 14, 15, 16(W). Geological Survey of Canada, Open File 3820, 2 maps in colour (Sheet 1: Ag, As, Au, Pb, Sb, Zn; Sheet 2: Co, Cr, Cu, Ni). [Scale: 1:100 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic first vertical derivative map, Kedgwick, New Brunswick, NTS 21 O/11 / Carte de la dérivée première verticle

du champ magnétique, Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-1A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of apparent conductivity, Kedgwick, New Brunswick, NTS 21 O/11 / Carte de la conductivité apparente, Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-1B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Natural air absorbed dose rate map, Kedgwick, New Brunswick, NTS 21 O/11 / Carte du taux d'absorption naturel dans l'air, Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-1C / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1C; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Potassium map, Kedgwick, New Brunswick, NTS 21 O/11 / Carte du potassium, Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-1D / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1D; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Uranium map (eU), Kedgwick, New Brunswick, NTS 21 O/11 / Carte d'uranium (eU), Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-1E / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1E; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium map (eTh), Kedgwick, New Brunswick, NTS 21 O/11 / Carte du thorium (eTh), Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-1F / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1F; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium/potassium map (eTh/K), Kedgwick, New Brunswick, NTS 21 O/11 / Carte du thorium/potassium (eTh/K), Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-1G / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1G; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic anomaly map (residual total field), Kedgwick, New Brunswick, NTS 21 O/11 / Carte de l'anomalie magnétiques (champ total résiduel), Kedgwick, Nouveau-Brunswick, SNRC 21 O/11. New Brunswick Department of Natural

Resources and Energy, Minerals and Energy Division, Plate 2000-1H / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-1H; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/11a, b / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/11a, b. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-5A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-5A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/11c, d / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/11c, d. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-6A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-6A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/11e, f / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/11e, f. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-7A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-7A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/11g, h / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/11g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-8A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-8A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

PRONK, A.G., FRISKE, P.W.B., MCCURDY, M.W., DAY, S.J.A., BOLDON, R. and DURHAM, C.C. 2000. National Geochemical Reconnaissance: Regional stream-sediment and water geochemical data, northwestern New Brunswick (NTS 21 O/12 and 21 O/13). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-6, 112 p. and digital data. Geological Survey of Canada, Open File 3889, 112 p.

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/11a, b / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/11a, b. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-5B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-5B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/11e, f / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/11e, f. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-6B / Ministère des Ressources naturelles et

de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-6B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/11e, f / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/11e, f. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-7B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-7B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/11g, h / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/11g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-8B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-8B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

21 O/12, Gounamitz River

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic first vertical derivative map, Gounamitz, New Brunswick, NTS 21 O/12 / Carte de la dérivée première verticle du champ magnétique, Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-2A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of apparent conductivity, Gounamitz, New Brunswick, NTS 21 O/12 / Carte de la conductivité apparente, Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natura¹ Resources and Energy, Minerals and Energy Division, Plate 2000-2B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Natural air absorbed dose rate map, Gounamitz, New Brunswick, NTS 21 O/12 / Carte du taux d'absorption naturel dans l'air, Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-2C / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2C; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Potassium map, Gounamitz, New Brunswick, NTS 21 O/12 / Carte du potassium, Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-2D / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2D; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Uranium map (eU), Gounamitz, New Brunswick, NTS 21 O/12 / Carte d'uranium (eU), Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-2E / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2E; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium map (eTh), Gounamitz, New Brunswick, NTS 21 O/12 / Carte du thorium (eTh), Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-2F / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2F; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium/potassium map (eTh/K), Gounamitz, New Brunswick, NTS 21 O/12 / Carte du thorium/potassium (eTh/K), Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-2G / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2G; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic anomaly map (residual total field), Gounamitz, New Brunswick, NTS 21 O/12 / Carte de l'anomalie magnétiques (champ total résiduel), Gounamitz, Nouveau-Brunswick, SNRC 21 O/12. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-2H / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-2H; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/12g, h / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/12 g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-8A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-8A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/12g, h / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/12g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-9B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-9B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Stream-sediment sample sites in the New Brunswick part of the Gounamitz River map area (NTS 21 O/12), northwestern New Brunswick / Points d'échantillonnage de sédiments fluviatiles dans la partie néo-brunswickoise du secteur cartographique de Gounamitz River (SNRC 21 O/12), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-21A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-21A. [Scale / Échelle : 1:50 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Cu, Co, Ni and Cr content of stream-sediment samples for the New Brunswick part of the Gounamitz River map area (NTS 21 O/12), northwestern New Brunswick / Teneur en Cu, Co, Ni et Cr des échantillons de sédiments fluviatiles de la partie néo-brunswickoise du secteur cartographique de Gounamitz River (SNRC 21 O/12), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-21B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-21B. [Scale / Échelle : 1:50 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Au, As, Sb, Ba and W content of stream-sediment samples for the New Brunswick part of the Gounamitz River map area (NTS 21 O/12), northwestern New Brunswick / Teneur en Au, As, Sb, Ba et W des échantillons de sédiments fluviatiles de la partie néo-brunswickoise du secteur cartographique de Gounamitz River (SNRC 21 O/12), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-21C / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-21C. [Scale / Échelle : 1:50 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Cu, Pb, Zn, Ag, and Mo content of stream-sediment samples for the New Brunswick part of the Gounamitz River map area (NTS 21 O/12), northwestern New Brunswick / Teneur en Cu, Pb, Zn, Ag, et Mo des échantillons de sédiments fluviatiles de la partie néo-brunswickoise du secteur cartographique de Gounamitz River (SNRC 21 O/12), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-21D / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-21D. [Scale / Échelle : 1:50 000]

21 O/13, States Brook

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic first vertical derivative map, States Brook, New Brunswick, NTS 21 O/13 / Carte de la dérivée première verticle du champ magnétique, States Brook, Nouveau-Brunswick, SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of apparent conductivity, States Brook, New Brunswick, NTS 21 O/13 / Carte de la conductivité apparente, States Brook, Nouveau-Brunswick, SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Natural air absorbed dose rate map, States Brook, New Brunswick, NTS 21 O/13 / Carte du taux d'absorption naturel dans l'air, States Brook, Nouveau-Brunswick, SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3C / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3C; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Potassium map, States Brook, New Brunswick, NTS 21 O/13 / Carte du potassium, States Brook, Nouveau-Brunswick,

SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3D / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3D; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Uranium map (eU), States Brook, New Brunswick, NTS 21 O/13 / Carte d'uranium (eU), States Brook, Nouveau-Brunswick, SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3E / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3E; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium map (eTh), States Brook, New Brunswick, NTS 21 O/13 / Carte du thorium (eTh), States Brook, Nouveau-Brunswick, SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3F / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3F; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium/potassium map (eTh/K), States Brook, New Brunswick, NTS 21 O/13 / Carte du thorium/potassium (eTh/K), States Brook, Nouveau-Brunswick, SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3G / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3G; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic anomaly map (residual total field), States Brook, New Brunswick, NTS 21 O/13 / Carte de l'anomalie magnétiques (champ total résiduel), States Brook, Nouveau-Brunswick, SNRC 21 O/13. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-3H / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-3H; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/13a, b / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/13a, b. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-10A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-10A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/13g, h / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/13g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-11A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-11A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/13a, b / Carte des conducteurs et de la

conductivité apparente, Nouveau-Brunswick, SNRC 21 O/13a, b. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-10B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-10B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/13g, h / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/13g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-11B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-11B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Stream-sediment sample sites in the New Brunswick part of the States Brook map area (NTS 21 O/13), northwestern New Brunswick / Points d'échantillonnage de sédiments fluviatiles dans la partie néo-brunswickoise du secteur cartographique de States Brook (SNRC 21 O/13), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-22A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-22A. [Scale / Échelle : 1:50 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Cu, Co, Ni and Cr content of stream-sediment samples for the New Brunswick part of the States Brook map area (NTS 21 O/13), northwestern New Brunswick / Teneur en Cu, Co, Ni et Cr des échantillons de sédiments fluviatiles de la partie néo-brunswickoise du secteur cartographique de States Brook (SNRC 21 O/13), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-22B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-22B. [Scale / Échelle : 1:50 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Au, As, Sb, Ba and W content of stream-sediment samples for the New Brunswick part of the States Brook map area (NTS 21 O/13), northwestern New Brunswick / Teneur en Au, As, Sb, Ba et W des échantillons de sédiments fluviatiles de la partie néo-brunswickoise du secteur cartographique de States Brook (SNRC 21 O/13), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-22C / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-22C. [Scale / Échelle : 1:50 000]

PRONK, A.G. and/et FRISKE, P.W.B. 2000. Cu, Pb, Zn, Ag, and Mo content of stream-sediment samples for the New Brunswick part of the States Brook map area (NTS 21 O/13), northwestern New Brunswick / Teneur en Cu, Pb, Zn, Ag, et Mo des échantillons de sédiments fluviatiles de la partie néo-brunswickoise du secteur cartographique de States Brook (SNRC 21 O/13), nord-ouest du Nouveau-Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-22D / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-22D. [Scale / Échelle : 1:50 000]

21 O/14, Menneval

FRISKE, P.W.B., DAY, S.J.A., PRONK, A.G., MCCURDY, M.W. and BOLDON, R. 1999. Regional Geochemical Reconnaissance—Multi-element stream sediment data plot: Restigouche area, New Brunswick, NTS

21 O/10, 11, 14, 15, 16(W). Geological Survey of Canada, Open File 3820, 2 maps in colour (Sheet 1: Ag, As, Au, Pb, Sb, Zn; Sheet 2: Co, Cr, Cu, Ni). [Scale: 1:100 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic first vertical derivative map, Menneval, New Brunswick, NTS 21 O/14 / Carte de la dérivée première verticle du champ magnétique, Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of apparent conductivity, Menneval, New Brunswick, NTS 21 O/14 / Carte de la conductivité apparente, Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Natural air absorbed dose rate map, Menneval, New Brunswick, NTS 21 O/14 / Carte du taux d'absorption naturel dans l'air, Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4C / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4C; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Potassium map, Menneval, New Brunswick, NTS 21 O/14 / Carte du potassium, Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4D / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4D; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Uranium map (eU), Menneval, New Brunswick, NTS 21 O/14 / Carte d'uranium (eU), Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4E / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4E; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium map (eTh), Menneval, New Brunswick, NTS 21 O/14 / Carte du thorium (eTh), Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4F / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4F; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Thorium/potassium map (eTh/K), Menneval, New Brunswick, NTS 21 O/14 / Carte du thorium/potassium (eTh/K), Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4G / Ministère des Ressources naturelles et de l'Énergie du Nouveau-

Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4G; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Magnetic anomaly map (residual total field), Menneval, New Brunswick, NTS 21 O/14 / Carte de l'anomalie magnétiques (champ total résiduel), Menneval, Nouveau-Brunswick, SNRC 21 O/14. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-4H / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-4H; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:50 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/14a, b / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/14a, b. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-12A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-12A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/14c, d / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/14c, d. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-13A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-13A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/14e, f / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/14e, f. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-14A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-14A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Aeromagnetic total field map, New Brunswick, NTS 21 O/14g, h / Carte aéromagnétique du champ total, Nouveau-Brunswick, SNRC 21 O/14g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-15A / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-15A; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/14a, b / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/14a, b. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-12B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-12B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/14c, d / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/14c, d. New Brunswick Department of Natural

Resources and Energy, Minerals and Energy Division, Plate 2000-13B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-13B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/14e, f / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/14e, f. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-14B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-14B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

KISS, F., CARSON, J., MCCUTCHEON, S.R., ONESCHUK, D., HOLMAN, P., GEOLOGICAL SURVEY OF CANADA. 2000. Map of conductors and apparent conductivity, New Brunswick, NTS 21 O/14g, h / Carte des conducteurs et de la conductivité apparente, Nouveau-Brunswick, SNRC 21 O/14g, h. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-15B / Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 2000-15B; Geological Survey of Canada, Open File 3784 / Commission géologique du Canada, Dossier public 3784. [Scale / Échelle : 1:20 000]

21 O/15, Atholville

FRISKE, P.W.B., DAY, S.J.A., PRONK, A.G., MCCURDY, M.W. and BOLDON, R. 1999. Regional Geochemical Reconnaissance—Multi-element stream sediment data plot: Restigouche area, New Brunswick, NTS 21 O/10, 11, 14, 15, 16(W). Geological Survey of Canada, Open File 3820, 2 maps in colour (Sheet 1: Ag, As, Au, Pb, Sb, Zn; Sheet 2: Co, Cr, Cu, Ni). [Scale: 1:100 000]

WILSON, R.A. 2000. Geology of the Popelogan Lake area (NTS 21 O/15a), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-25 [Scale: 1:20 000]

WILSON, R.A. 2000. Geology of the Lost Pine Lake area (NTS 21 O/15b), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-26 [Scale: 1:20 000]

21 O/16, Charlo

FRISKE, P.W.B., DAY, S.J.A., PRONK, A.G., MCCURDY, M.W. and BOLDON, R. 1999. Regional Geochemical Reconnaissance—Multi-element stream sediment data plot: Restigouche area, New Brunswick, NTS 21 O/10, 11, 14, 15, 16(W). Geological Survey of Canada, Open File 3820, 2 maps in colour (Sheet 1: Ag, As, Au, Pb, Sb, Zn; Sheet 2: Co, Cr, Cu, Ni). [Scale: 1:100 000]

21 P, BATHURST

PHILLIPS, R.E. and ST. PETER, C. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999; Bathurst: map sheet 21 P . New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-20F. [Scale: 1:250 000]

ST. PETER, C. and PHILLIPS, R. 2000. Reflection seismic coverage of onshore and offshore New Brunswick, 1948–1999. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-7, 39 p. (parts of NTS 21 B, 21 G, 21 H, 21 I, 21 P)

21 P/02, Point Escuminac

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 P/03, Chatham

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 P/04, Sevogle

DOIRON, A. 2000. Surficial geology, Big Bald Mountain–Sevogle, New Brunswick, NTS 21 O/01 and part of 21 P/04. Geological Survey of Canada, Map 1977A [Scale: 1:50 000]

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 P/05, Nepisiguit Falls

LENTZ, D.R. 1999. Petrology, geochemistry and oxygen isotope interpretation of felsic volcanic and related rocks hosting the Brunswick 6 and 12 massive sulfide deposits (Brunswick Belt), Bathurst mining camp, New Brunswick, Canada. Economic Geology, **94**: 57–86.

LENTZ, D.R. 1999. Deformation-induced mass transfer in felsic volcanic rocks hosting the New Brunswick No. 6 massive-sulfide deposit, New Brunswick, Canada: geochemical effects and petrogenetic implications. The Canadian Mineralogist, **37**: 489–512.

PARKHILL, M.A. and DICKSON, M.L. 1999. Till geochemistry of the Nepisiguit Falls map area (NTS 21 P/05), Gloucester and Northumberland counties, New Brunswick: site and geochemical data. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-10, 108 p. and digital data.

VAN STAAL, C.R. 2000. Geology, northern half of the Bathurst Mining Camp (part of NTS 21 O/07, 8, 9, 10, 21 P/5, 12), New Brunswick. Geological Survey of Canada, Open File 3839, 8 maps in colour. [Scale: 1:20 000]

21 P/06, Tabusintac River

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 P/07, Wishart Point

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 P/10, Tracadie

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 P/11, Burnsville

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

21 P/12, Bathurst

VAN STAAL, C.R. 2000. Geology, northern half of the Bathurst Mining Camp (part of NTS 21 O/07, 8, 9, 10, 21 P/5, 12), New Brunswick. Geological Survey of Canada, Open File 3839, 8 maps in colour. [Scale: 1:20 000]

21 P/13, Pointe Verte

NORANDA INC. 2000. Slag fuming at Belledune, New Brunswick: Phase I summary report and Phase II proposal. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-2, 140 p.

21 P/15, Caraquet

BÉRUBÉ, D. 1999. Étude photogrammétrique du déplacement de la ligne de côte de la flèche de Maisonnette, baie de Caraquet, Nouveau-Brunswick : 1944–1991. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 99-29B [Échelle : 1:10 000]

BÉRUBÉ, D. 1999. Étude photogrammétrique du déplacement de la ligne de rivage de la flèche de Maisonnette, baie de Caraquet, Nouveau-Brunswick : 1944–1991. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, Planche 99-29A [Échelle : 1:10 000]

ST. PETER, C. 2000. Catalogue of well data for boreholes in the Maritimes Basin and Fundy Subbasin, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 2000-5, 235 p. and digital data.

Conversion Factors:
Imperial and International System of Units (SI)

The following multipliers should be used to convert imperial units to SI units or SI units to imperial units:

CONVERSION FROM SI TO IMPERIAL			CONVERSION FROM IMPERIAL TO SI		
SI Unit	*Multiply by*	*Gives*	*Imperial Unit*	*Multiply by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.32 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

NOTE: Conversion factors in bold type are exact.

SOURCE: Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by The Mining Association of Canada in cooperation with the Coal Association of Canada.